THE PEGASUS BAY RIG FISHERY:

MANAGEMENT FOR OPTIMUM YIELD

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ABSTRACT

The Pegasus Bay rig fishery is a small but complex set net fishery. It is one of the four main fisheries exploiting the South Island east coast rig stock. The goal of this study is to determine how the fishery could be managed for optimum yield.

The fishery is shown to be in a very serious biological state. Rig abundance is declining rapidly as a result of severe overfishing. At present, the trawl by-catch alone exceeds the estimated sustainable yield. It seems likely, however, that other species in the area can be exploited by set net fishermen without being overfished. The fishery is also in a serious economic condition. Economic and financial returns from the fishery are both very low. Further set net fishing on the scale presently practiced can be expected to generate significant economic losses in the near future.

Five key elements of the optimum yield are recognised for this fishery: biological sustainability, economic efficiency, the provision of reasonable incomes for fishermen, the complexity of management regulations, and the cost of managing the fishery. It is concluded that two steps are necessary to attain the optimum yield. The first is a reduction in the number of vessels in the fishery. The second is a redistribution of fishing effort off rig and on to other species. Various management measures for achieving these two requirements are outlined.

1.0 INTRODUCTION

1.1 THE NEW ZEALAND INSHORE FISHING INDUSTRY

Fishing is deeply embedded in New Zealand's history, both as a way of life and as a means of earning a living. It figured strongly in Maori culture long before the arrival of Europeans, and lives on today as an important part of the New Zealand lifestyle and economy. The inshore industry is presently in a very serious state, however. Many fish stocks are under intense pressure and a large number of fishermen are in considerable financial difficulty. These problems have either arisen or been aggravated by very rapid growth in the size of the domestic fleet in recent years, particularly since the mid 1970s.

The mid and late seventies were an unprecedented era of expansion and growth in the New Zealand fishing industry (see Figure 1.1). Amidst great excitement and enthusiasm about the imminent declaration of a 200-mile Exclusive Economic Zone (EEZ), the industry was encouraged to "think big" by the Minister of Fisheries, Mr MacIntyre. This it certainly did. Many new and large vessels were imported, particularly after 1977 when the government relaxed import restrictions.

While the general desire to expand and exploit the offshore resources was admirable, it was too early to be encouraging investment in this sector, as too little was known about the resources and their markets (Jarman, 1983). The result was that expansion occurred, but not in the anticipated areas. As Jarman (1983) notes,

"We did not develop a deepwater catching capacity at this time, but increased effort in the inshore fisheries, because we acquired vessels which were large only when compared with small coastal vessels, but which were themselves too small to tap the waters further out."

Since the new vessels had considerable catching power, effort rose dramatically in the inshore fisheries. This occurred at a time when many of the fisheries were already being overfished. Thus a number of the coastal fisheries came under intense fishing pressure during this time.

In response to the growing pressure on inshore stocks, the government

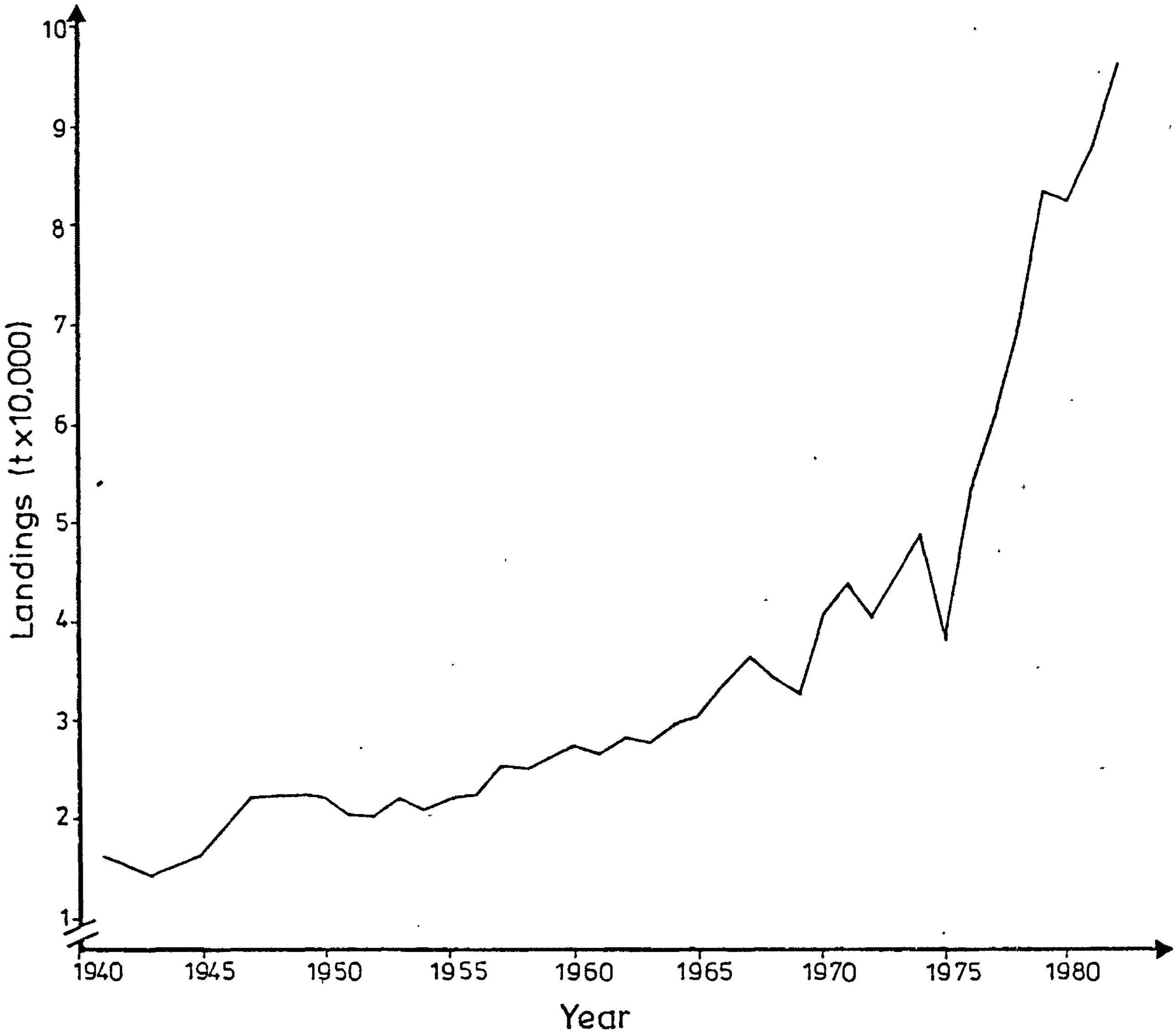

Figure 1.1 Total domestic wetfish landings, 1941-1982 (Source: Ritchie *et al.*, 1975; MAF, unpubl. data).

passed the Fisheries Amendment Act in 1977. This act provided for the declaration of controlled fisheries. Although it was employed to curb effort in the rock lobster fishery and in several important shellfish fisheries, it was only once used for a wetfish fishery. For the vast majority of fisheries, therefore, effort was unabated and it continued to increase.

The consequences of this pressure were severe. In some fisheries, the pressure was so great that the stocks collapsed. In many others, it reduced species to very low levels of abundance. As catches fell and costs continued to increase, many fishermen began to experience financial difficulties. Overall, the fishing industry entered a serious economic recession.

With the situation still deteriorating and reaching crisis proportions in many areas, the government announced a national moratorium on the issue of any further fishing permits on 18 March 1982. The moratorium applies to all domestic vessels harvesting species other than tuna outside Area G of the EEZ, squid and seaweed (Anon, 1982b). The purpose of the moratorium was to prevent any further increases in fishing effort, while suitable management was implemented to reduce pressure on the fish stocks. This management has not yet been fully implemented and so the moratorium is still in place at present.

The most significant management-related events which have occurred since the moratorium was introduced are: first, the release of a discussion document on future policy for the inshore fisheries; second, the passing of a new Fisheries Act; third, the exclusion from the industry of individuals who do not meet the definition of a commercial fisherman[1]; and fourth, the cancellation of fishing permits which have not been used in the last two years.

Since large effort reductions are required in most regions, it became clear that there was a need for a national policy on both effort reduction and long-term stabilisation of the industry. As a first step in developing this policy, the Ministry of Agriculture and Fisheries (MAF) and the New Zealand Fishing Industry Board (NZFIB) prepared a paper for the National

[1] The term "commercial fisherman" is formally defined in the Fisheries Act (1983). To meet this definition, fishermen must satisfy certain criteria which have been laid down by the Director-General.

Fisheries Management Advisory Committee (NAFMAC) on the state of the resource and industry, and possible policy options for alleviating the present problems. This paper contained no proposals or recommendations as it was only written to promote public discussion. It was released in August 1983 and was immediately followed up by public meetings throughout the country.

The paper produced for the committee provides a very graphic description of the seriousness of the present situation. The main conclusion to emerge from the assessment of the state of the industry, is that there must be large catch and effort reductions in many fisheries to ensure the long-term biological and economic well-being of the industry. It is estimated in the report that the capital invested in the full-time domestic fleet of less than 30 m in length, must be reduced by approximately $28 million. This represents about 20% of the total capital currently invested in this part of the fleet. On the east coast of the North Island, the area where most excess fishing effort exists, the required reduction is equal to approximately 44% of the existing investment in these vessels.

The magnitude of the required catch reductions is even more alarming. It is estimated that present catches of many prime species must be cut dramatically to enable stocks to recover; 65% for rig (*Mustelus lenticulatus*), 63% for trevally (*Caranx georgianus*), 44% for snapper (*Chrysophrys auratus*) and tarakihi (*Nemadactylus macropterus*), and 32% for gropers (mainly *Polyprion oxygeneios*). Even after a recovery period, catches of many species must be far less than current harvests, e.g., 63% for rig. These national estimates disguise the severity of many of the regional problems, however. The required reduction for rig on the Canterbury coast, for instance, is 75%, and in the Bay of Plenty snapper, trevally, gropers and rig catches must be reduced by 77%, 66%, 66% and 60% respectively in the short-term. What is even more disturbing is that these reductions must be made quickly. The report states that,

> *"Failure to take action will not only result in a biological and commercial fishing disaster in the very near future, but it will also ensure the consequential economic collapse of a large part of the inshore fishing industry."*

The second major management-related event occurred on 1 October 1983 when the long-awaited new Fisheries Act became effective. This is a consolidating act and supersedes all previous fisheries legislation. Most of the provisions of previous acts still stand under the new act, but some significant changes have been introduced. One of the major changes has been to shift management control from a central to a regional basis. This has been done,

> "... *to develop management systems which are dynamic and [which] can be quickly brought into effect, changed and modified....*".
>
> (Cunningham, 1983)

Thus, most fisheries will now be managed on a regional basis, using either the controlled fisheries or fisheries management plan provisions. Some fisheries may still be managed on a national basis, as there may be instances where this will be more appropriate. The great majority of fisheries will probably be managed under a fishery management plan, however. The process by which such a plan is developed and the factors which must be taken into account when preparing it are laid out in the act.

When the act became effective, it automatically cancelled all vessel registrations, licences and permits. To be entitled to re-register a vessel and obtain the appropriate fishing permit or licence, a fisherman had to meet the definition of a commercial fisherman. Those who did not satisfy the Director-General's criteria have been excluded from all commercial fishing activities. Thus, the first step in the effort reduction process has now been implemented. Another step, the cancellation of all permits which have not been used in the last two years, has also been implemented recently. Further steps will follow in the near future.

Although the present situation is serious, the NZFIB is optimistic about future development prospects in the coastal sector. It believes that,

> "... *there are opportunities for inshore fishermen to exploit currently under-utilised inshore species....*"
>
> (Anon, 1982a)

and that,

> "*Rational development of presently under-utilised resources must continue and be further encouraged.*"
>
> (Anon, 1982a)

Most future development is, however, likely to be of a fundamentally different nature as it will almost certainly be achieved through redeployment of existing fishing effort, rather than through the introduction of new vessels. This will help to reduce pressure on the stressed fisheries and at the same time help fishermen to protect their stake in the industry.

1.2 THE DEVELOPMENT OF RIG (*Mustelus lenticulatus*) FISHERIES

Target rig fisheries are a very recent development in the fishing industry. Although it was well known for many years that rig are seasonally abundant around a large part of the coastline, the species was only lightly exploited in most areas until the early 1970s (Mace, 1981). There are several reasons for this, but one of the most important stems from New Zealanders' long-standing prejudice against shark flesh. While the Maori and several overseas nations value many cartilaginous fish highly, New Zealand Europeans have traditionally held them in very low esteem (Hector, 1872; Phillipps, 1949; Holden, 1974).

For a long time, therefore, rig was labelled as a "dogfish" or "shark" with the result that it met strong consumer resistance. Despite such resistance, it was sometimes sold in appreciable quantities, both in the fast-food trade and in the retail trade. In the retail trade, it was (and still is) usually disguised under various trade names such as "lemonfish", "flake" or "silver strip" (Parrott,1958). As well as being a source of food, it also yielded valuable by-products such as leather from the skin and oil from the liver, and for a while the fins were sold to the Chinese for making soup (Parrott,1958). Nevertheless, the demand was limited and with the catch being of low value compared to the more preferred species (Graham, 1956), there was probably little incentive for fishermen to actively pursue the species prior to the 1970s. It remained a by-catch, therefore, principally from trawling, but also to a lesser extent from set netting (Watkinson and Smith, 1972; Francis and Mace, 1980; Mace, 1981).

During the early seventies, this pattern changed rapidly as a number of factors suddenly stimulated the development of rig fisheries. Of prime importance was the declining profitability of many other fisheries. Francis (1979) notes that the Kaikoura fishery developed from reduced catches of butterfish (*Odax pullus*), and in Pegasus Bay, it developed from the reduced abundance of elephant fish (*Callorhynchus milii*) (A. Coakley, pers. comm.). These declines, coupled with an increased demand for the species (particularly in the fast-food trade), resulted in much higher prices being paid for rig. Thus, there was a double incentive for fishermen to now target fish for the species in many areas.

Technological factors were also an important stimulus to the development of these fisheries. At about the same time as the above changes were occurring, there were several advances in set net technology which made this method of fishing much more attractive to fishermen. With the introduction of monofilament nylon mesh, set nets became much more efficient in terms of their ability to catch fish than they had been when cotton mesh was in use. The introduction of mechanical net hauling equipment was also significant as it enabled fishermen to work more net. With this equipment, fishermen could also fish in deeper water than had been possible with hand-hauled nets.

All of these advances greatly increased the catching power of set nets and, as a result, set net fishing became much more profitable. This made it much more attractive to fishermen and, consequently, the set net fleet underwent considerable expansion (Mace, 1981). Although many vessels switched to netting from trawling (especially in the Canterbury Bight) or dredging (especially in Tasman Bay - Golden Bay), there were also a lot of small, high-speed boats built specifically for set netting (Mace, 1981). Since rig was not a relatively high-value species, a large number of these new and converted vessels began fishing for rig. Technological and economic incentives were, therefore, a very powerful stimulus to the development of rig fisheries and they may largely explain the reason for such rapid development.

Once rig became target fished by set net fishermen, set netting began to displace trawling as the dominant method of capture for this species (see Figure 1.3). In 1971, only 20% of all rig were taken by set net, while 75% were taken by trawl (MAF, unpubl. data). In 1978, however, 63% of the total New Zealand rig catch was taken by set net, with trawl only providing 34% of the catch (MAF, unpubl. data). Set netting has since displaced trawling even further as the dominant method of rig capture (see Figure 1.3).

The increased landings that resulted from this development very quickly elevated rig from its former lowly status. Between 1970 and 1978

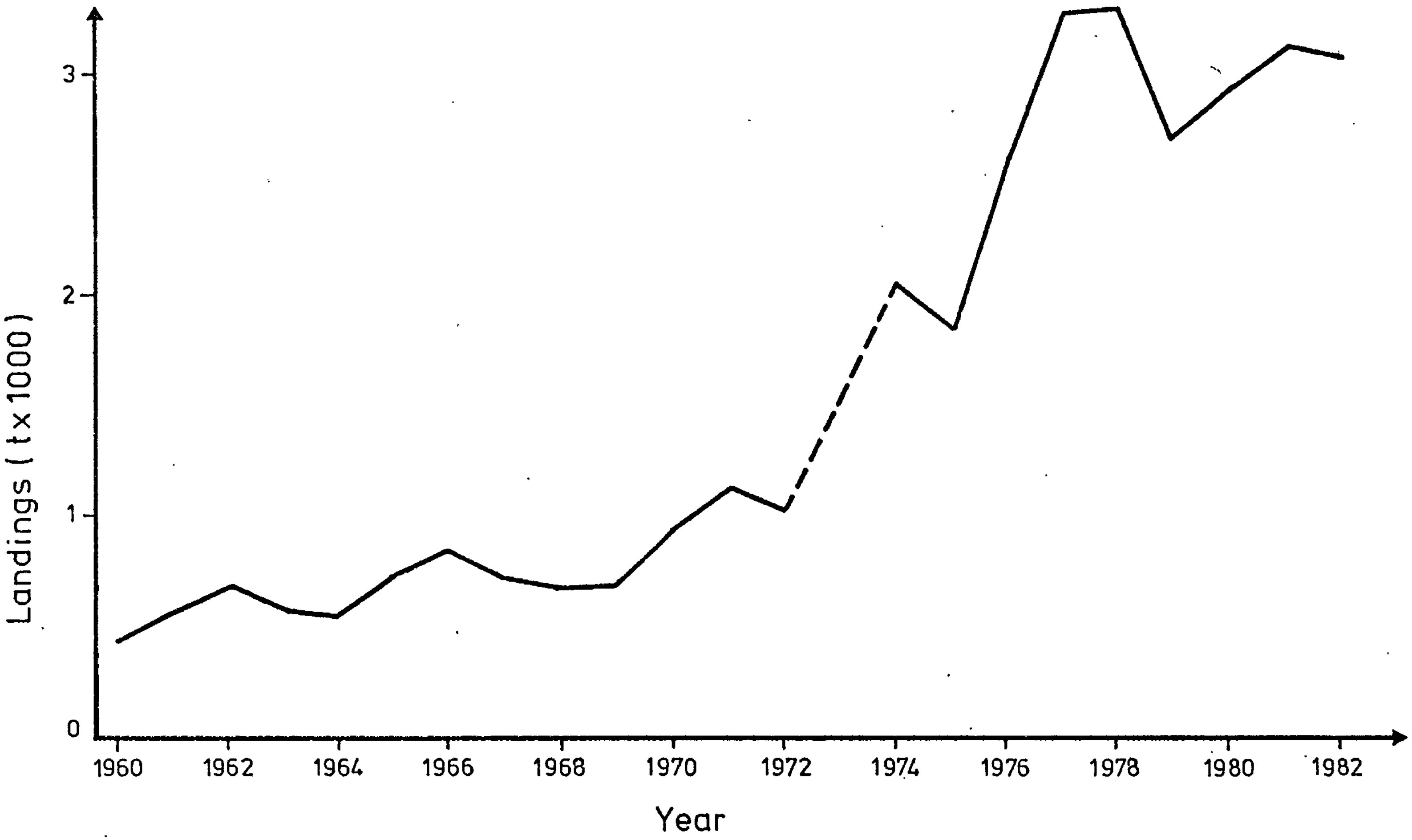

Figure 1.2 New Zealand pioke landings, 1960-1982 (Ritchie *et al.*,1975; MAF, unpubl. data).

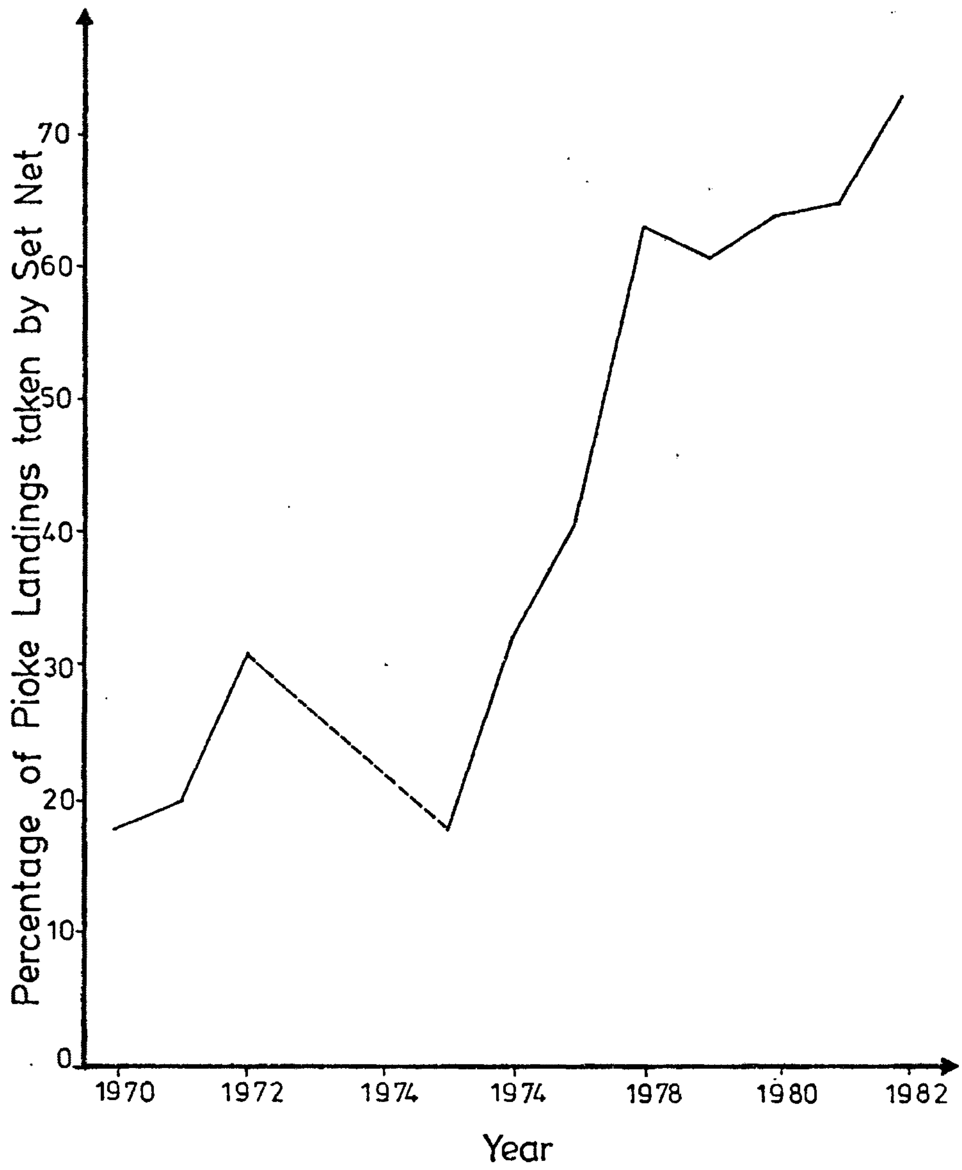

Figure 1.3 Percentage of New Zealand pioke landings taken by set net, 1970-1982 (Source: MAF, unpubl. data).

the national pioke[1] catch rose from 930 to 3299 tonnes (t) and its contribution to the national wetfish landings increased from 2.3% to 4.5% (Ritchie *et al.*, 1975; MAF, unpubl. data). Although catches have fallen since 1978, it still remains an important species. In 1982, the total New Zealand rig catch was 3183 t, making it the tenth most important species by weight for the New Zealand domestic fleet. Data are not available on the value of the 1982 catch, but in 1981 when rig was the ninth most important species by weight, the species was the sixth most important by value for the domestic fleet.

1.3 EXPLOITATION OF ELASMOBRANCHS

1.3.1 Characteristics of Elasmobranchs

Contemporary jawed fishes can be organised into two separate evolutionary lines. One line, the class *Chondrichthyes*, contains species with a cartilaginous skeleton, while the other, the class *Osteichthyes*, has species with at least a partly ossified internal skeleton (Villee *et al.*, 1973). These two groups have been evolving separately for about 400 million years and they have some important biological differences. The two differences which have the greatest significance for management are differences in the growth and reproductive characteristics of each group. Since very little work has been done on the holocephalans[2], however, the discussion of these characteristics will be confined to elasmobranchs[2].

Elasmobranchs appear to have only low to moderate growth rates. Holden (1974) assumed that all sharks have low growth rates, but this assumption is incorrect. A number of smaller sharks have von Bertalanffy growth constants in the range 0.3 - 0.48 (Francis, 1981). These constants are considerably larger than those for the shark species investigated by Holden (e.g., the school shark, *Galeorhinus australis*, and the spiny dogfish, *Squalus acanthias*) and they indicate that some of the smaller sharks at least have moderate growth rates (M. Francis, pers. comm.). Thus, while not all elasmobranchs grow slowly, most probably only have low to moderate growth rates. This contrasts with teleost[3] species, which generally have moderate to fast growth rates.

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[1] "Pioke" is a collective term referring to rig and two dogfish species, *Squalus acanthias* and *S. blainvillei*. Most of the catch recorded as pioke would be rig, however (Watkinson & Smith, 1972; M. Francis, pers. comm.).

[2] Contemporary cartilaginous species are classified into two subclasses: Holocephali and Elasmobranchii. The subclass Elasmobranchii contains all sharks, skates and rays. Sharks, skates and rays comprise the vast majority of all living cartilaginous fish.

[3] The super-order Teleostei contains the majority of all familiar and commercially important bony fish (class *Osteichthyes*).

The second important characteristic of this group is their low fecundity. Fecundity is a function of both the number of offspring that are liberated at each spawning and the frequency of spawning.

Most sharks are either viviparous[1] or ovoviparous[1] breeders, but a few are oviparous[1]. Skates and rays are oviparous breeders (Villee *et al.*, 1973). The method of reproduction in oviparous elasmobranchs differs from that in the oviparous teleosts[2], however. The eggs produced by oviparous elasmobranchs are heavily laden with yolk and they are released into a protective capsule in which the young develop before being born (Villee *et al.*, 1973). In contrast, teleost eggs are small, and they are released directly into the water. Elasmobranchs are characterised, therefore, by the elimination of a free larval phase. The young are born live, as well-developed replicas of the adults.

Since a large amount of energy goes into producing each offspring in all elasmobranchs, only a few young may be produced in any one reproductive cycle. This contrasts with teleost species which frequently produce many thousands of eggs in each reproductive cycle. In viviparous and ovoviparous elasmobranchs, the number of offspring may be further constrained by the size of the maternal body cavity.

Many elasmobranch species do not mature until a moderate or late age. This compounds the problems of only a few young being produced during each reproductive cycle, and inhibits the reproductive capacity of these species even further. However, elasmobranch populations are assumed to be relatively stable (in the absence of fishing pressure) and so the low fecundity and low to moderate growth rates must be naturally balanced by other factors. Two of these factors might be low natural mortality rates and long reproductive lives of adults.

1.3.2 Implications of These Characteristics

The combination of these characteristics makes the task of managing elasmobranch populations very difficult. It makes elasmobranchs inherently

[1] In viviparous species, the young derive nourishment from their mother during *in utero* development. In ovoviparous species, development is also internal, but embryos are not nourished by the mother. It is frequently difficult to distinguish between these two forms of embryonic development however, as there are varying degrees of dependence on the mother. In oviparous species, eggs are extruded from the body and development is external.

[2] The great majority of all teleosts are oviparous breeders.

susceptible to overfishing and it also renders them incapable of sustaining heavy fishing pressure. The typical response to heavy pressure is a rapid decline in abundance. Holden (1974) states that,

> *"The history of the few shark fisheries for which records are available, suggests that ... initial exploitation is followed by, at best, a rapid decline in catch rates or, at worst, a complete collapse of the fishery."*

The very same characteristics which make elasmobranchs vulnerable to overfishing also make them slow to recover when fishing pressure is relieved.

In a virgin fish population, a large proportion of the fish are old and either slow-growing or not growing at all. Juvenile mortality is also high. When fishing occurs, both the biomass and average age of fish are reduced. If the food supply remains constant, then fishing will increase annual production in the population: first, because there will be more food for each fish, and second, because younger fish use a greater proportion of their food for growth than do older fish (Idyll, 1952). If fishing intensity is too great, however, then the quantity of fish removed from the population will exceed that which can be added through growth and recruitment (Francis, 1983b). Too many fish will be caught too early in their lives and maximum harvest potentials will not be realised (R. Francis, 1979). This type of overfishing is known as growth overfishing.

Since elasmobranchs have only low to moderate growth rates and low fecundity, the rate of production in elasmobranch populations is low. This means that maximum harvest potentials are also comparatively low, even when the standing stock is high. The corollary to this is that the standing stock needs to be maintained at a high level if the stock is to produce even low sustainable yields. Thus, it is easy to exceed the maximum harvest potential and fish the standing stock down and, hence, the reason why elasmobranchs are so susceptible to growth overfishing.

Elasmobranchs are also very susceptible to a second type of overfishing: recruitment overfishing. This type of overfishing occurs when pressure is so great that it reduces the number of recruits entering a fishery. When exploitation reaches this level, the productivity of the stock becomes seriously affected: first, because there are fewer adult fish to contribute to the population's growth increment, and second, because the population's reproductive capacity is reduced. The outcome of continued recruitment overfishing is a fishery collapse of one form or another (R. Francis, 1979).

The susceptibility of elasmobranchs to recruitment overfishing stems from two factors: the nature of their stock-recruitment relationship, and the nature of their size-fecundity relationship.

Since elasmobranchs are born at a large size, physical environmental factors probably have little effect on juvenile survival and recruitment (Holden, 1973). It is probable, therefore, that their low fecundity results in recruitment being more closely related to the size of the breeding stock than to environmental factors. Thus, elasmobranchs are thought to have a direct stock-recruitment relationship (Holden, 1973, 1974; Royce, 1975), as shown in Figure 1.4.

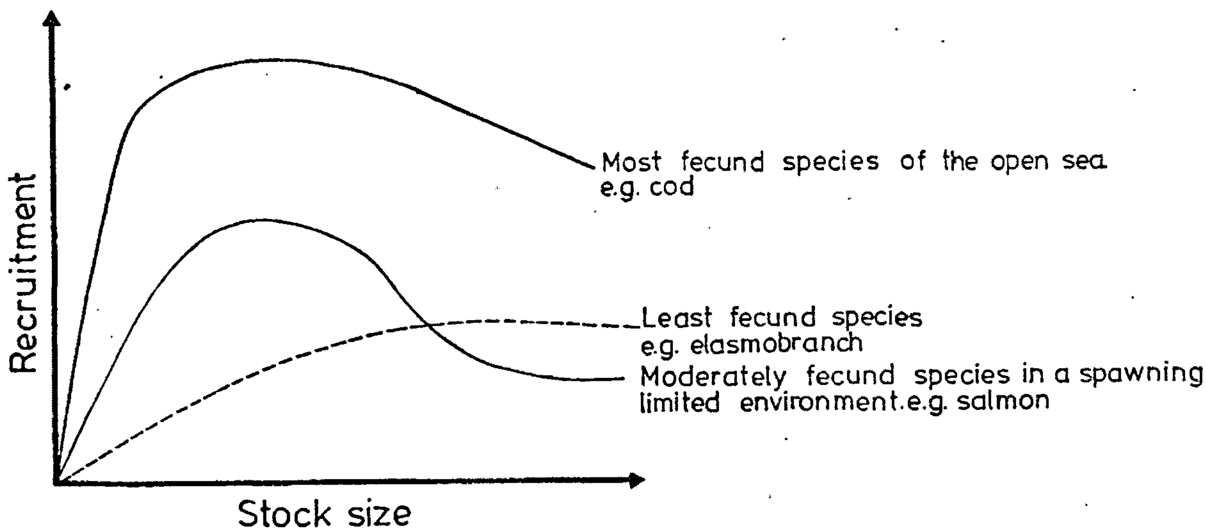

Figure 1.4 Stock-recruitment relationships of low, moderate, and high fecundity species. (After Royce, 1975)

The implication of a direct stock-recruitment relationship is that recruitment will be affected if the number of mature females in a stock is reduced far below natural population levels (Holden, 1973, 1974). Thus, recruitment overfishing will occur at much lower levels of exploitation for elasmobranchs than it will for teleosts as teleosts do not have a direct stock-recruitment relationship (Ricker, 1954). For teleost species, the abundance of females must be greatly reduced before recruitment will be affected. It can be seen from the figure that with teleost species a reduced stock may actually improve recruitment and recruitment may still be high at low population levels.

Fecundity appears to increase with female size in all elasmobranch species which have been studied so far (Holden, 1974; Francis, 1979). Since fishing reduces the average size of fish in a population, the mean number of young per female will also decline as fishing pressure increases (Francis, 1983b).

Thus, fishing reduces both the number of mature females in a stock and the mean number of young per female. Because elasmobranchs have a low fecundity, and probably also have a direct stock-recruitment relationship, the combined effect of these two factors can very rapidly lead to recruitment failure in elasmobranch fisheries.

The other reason why elasmobranchs are not resilient to fishing pressure is because they may not have a very great density-dependent production response. Since their growth rates are only low to moderate, the potential for growth-induced production compensation is probably not great. The fecundity-induced compensation response is probably also very limited because of the high energy demand of each offspring (Holden, 1977). Furthermore, the size of the maternal body cavity may impose a restriction on the extent of any response for viviparous and ovoviparous species. It should be noted that an increase in fecundity may not result in a proportional increase in abundance, as the fecundity increase may result in a smaller birth size of the offspring (Holden, 1977). This could increase the risk of predation. Even these modest responses will only be achieved, however, if pressure is applied slowly, as the stock needs time to respond to changes in abundance (Holden, 1977).

It may be concluded, therefore, that the biological characteristics of elasmobranchs are of profound importance for management. They dictate that fishing effort must be applied slowly and cautiously, and, furthermore, that the stock (particularly the female portion of the stock) must be given considerable protection from heavy exploitation. Given the speed with which modern fishing fleets can expand, this inevitably makes the task of managing elasmobranch stocks very difficult.

1.4 STUDY OUTLINE

During the planning stages of this study, it became evident that the Pegasus Bay rig fishery would probably be managed under a fishery management plan. Although the concept of managing fisheries through regional plans had not been legally approved at that stage, the approval seemed imminent in the new act. The approval was given in the new act and interim management plans are due to be completed by July 1984. Longer-term plans are due for completion in about three years. Thus, the study has been oriented towards considering how the fishery could be managed under a fishery management plan. The management measures contained in the study are suggested short-term measures for the interim plan. No attempt is made to determine appropriate long-term measures for reasons which are outlined later.

One of the important features of fisheries is that they are very complex and dynamic systems. Since the components of a fishery system are of a diverse nature, so too is the information that is required to understand the fishery. The application of multidisciplinary skills and attitudes and the integration of diverse types of information are all key requirements of a rational fisheries management framework, therefore. It is only by obtaining and integrating information on the many different aspects of a fishery that it is possible to understand the fishery's problems and to anticipate the likely consequences of management. The approach used in this study, therefore, is to examine as many aspects of the Pegasus Bay rig fishery as possible to try to understand the problems in the fishery. This information is then used to determine appropriate management measures for the fishery. The goal of the study is to determine how the Pegasus Bay rig fishery could be managed for optimum yield.

The investigation begins in chapter 2 with a description of three aspects of the fishery: the area, the biology of rig, and the commercial enterprise. The description of the commercial enterprise contains information on the importance and the history of the fishery. It concludes with a description of the fishery as it existed in the 1982-83 season.

Chapters 3, 4 and 5 examine biological and economic aspects of the fishery to obtain a picture of its present state. An analysis of commercial catch and effort data is presented in chapter 3. The biological states of other rig fisheries which exploit the same rig stock are also briefly discussed in the discussion section of this chapter to aid interpretation of the results. Chapter 4 contains the results of a biological investigation which was carried out over the 1982-83 season. The length, sex and maturity compositions of commercial rig catches are all described. Growth and reproductive characteristics of rig sampled from commercial catches are also discussed. Chapter 5 contains a description of the financial and economic states of the fishery. Attention is given to comparing the profitability of the three groups of operations identified in chapter 2.

Chapter 6 completes the study with a discussion of management for the fishery. The concept of optimum yield is discussed at the beginning of the chapter. Some important elements of the optimum yield are also identified. Information from the previous chapters is then synthesised to provide an overall assessment of the state of the fishery and the implications of non-management. Finally, the study concludes with a personal opinion on the short-term optimum yield for the fishery. The optimum yield is described in terms of the size of the physical yields, the amount of fishing effort, allocation of the yields and management to attain the optimum yield.

2.0 THE PEGASUS BAY RIG FISHERY

2.1 PEGASUS BAY

2.1.1 Location

Pegasus Bay is situated off the Canterbury coast immediately north of Banks Peninsula (see Figure 2.1). The northern and southern limits to the bay are at Motunau Island and East Head respectively (New Zealand Pilot, 1946), with Motunau Island lying some 70 km north of East Head.

The shoreline between these two points is topographically varied. Between Motunau Island and Double Corner (19 km west-south-west of Motunau), the coast is bordered by cliffs, with sandy and stony beaches being exposed at low tide (Dawson, 1954). From Double Corner to the South Brighton spit these beaches are replaced by a 42 km dune beach running along the front of the Canterbury plains. Two major rivers, the Waimakariri and Ashley rivers, and two minor rivers, the Kowhai and Waipara rivers, flow into Pegasus Bay along this beach. The Avon-Heathcote estuary also opens out into the bay at the southern end of the beach. From here the coast runs along the northern side of Banks Peninsula out to East Head some 40 km east-south-east of the estuary. The coastline along this part of the bay is pitted with a number of harbours and inlets, the largest of which is Lyttelton Harbour. Unlike the rest of the shoreline around Pegasus Bay, much of this is composed of muddy beaches and rocky promontories.

2.1.2 Bathymetry

Most of Pegasus Bay has a very regular bathymetry (see Figure 2.1). Almost the entire seabed in the bay gently slopes from a depth of approximately 8-10 m one kilometre off shore, to approximately 100 m at the edge of the continental slope.

The one intrusion on this simplicity occurs where the Pegasus Canyon cuts into the Pegasus Bay shelf on the very outer margin of the bay. This complex canyon originates in deep water at the southern end of the Hikurangi trench and runs south-west before terminating about 40 km north-east of East Head on Banks Peninsula (Knox, 1969). At the edge of the canyon the seabed very rapidly plunges to depths in excess of 900 m.

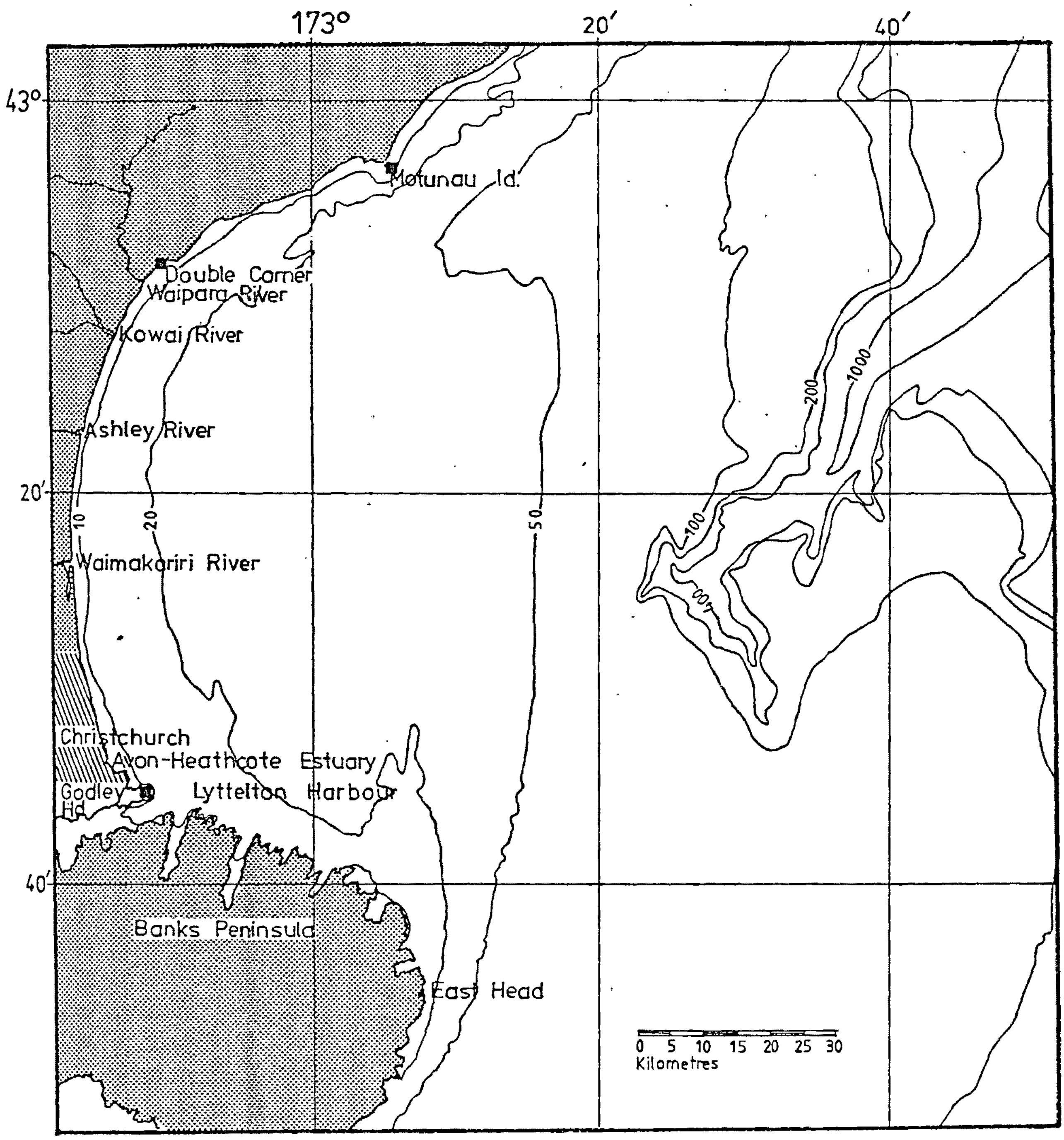

Figure 2.1 Pegasus Bay area and bathymetry. All depths are in metres. (Source: N Z Navy Map No 63, 1979).

2.1.3 Oceanography

Pegasus Bay is hydrologically bounded to the east by the Southland current, one of three major offshore coastal currents of New Zealand's east coast. The current originates south-west of Stewart Island and flows north between Banks Peninsula and the Mernoo Bank before branching near Kaikoura (Burling, 1961 *in* Heath, 1975; Heath, 1972a). On its way north past the bay, it passes within approximately 30 km of the land (Dawson, 1954; Brodie, 1960). Dawson (1954) and Brodie (1960) both observed that drift cards released less than 30 km offshore were retained in Pegasus Bay, while cards released between 30 and 100 km offshore were carried well out of the bay to various localities along the South Island, lower North Island and Chatham Islands.

Within the confines of the bay, the water movements are much more variable, as they are strongly influenced by local wind conditions (Dawson, 1954). Since they vary in accordance with both the strength and direction of the winds, the currents tend to vary throughout the year. The dominant movements are, however, towards the shore, as inshore currents are created by northerly-quarter winds and these are the most frequent winds on the North Canterbury coast (Dawson, 1954; Brodie, 1960). Offshore currents may occur during the winter, if southerly winds have prevailed for a time (Dawson, 1954). When this occurs the wind-driven current combines with the Southland current waters to create a clockwise water movement leading out of the bay (Dawson, 1954).

The temperature regime within the bay exhibits marked seasonal fluctuations, with maximum mean monthly temperatures occurring in January or February and minimum mean monthly temperatures in August (Garner, 1961). In comparison to the 4.5 - 5.0°C temperature range in the open sea, the seasonal temperature range within Pegasus Bay is usually about 8.5°C, although it may be as high as 12°C (Garner, 1961; Knox, 1969; Heath, 1975). The greater range results from the shallowness of the water and the effects of coastal sheltering (Garner, 1961; Heath, 1975). Garner (1961) also notes that,

> *"... maximum development in depth of vertical mixing in summer and convective overturn in winter may be inhibited in shallow coastal waters. This often results in high summer maximum temperatures and lower values during the winter minimum period relative to oceanic waters".*

Thus, although the annual range is high, it is not unduly so when compared to other semi-enclosed waters such as the Hauraki Gulf.

The salinity variation within Pegasus Bay may also be high, both spatially and temporally (Garner, 1961). In April 1952, salinities were found to be very high (i.e., 35.5‰) with little variation across the bay, while in December 1955 they were found to be very low (Garner, 1953, 1961). Salinities as low as 34.0‰ were also recorded in November 1968 and July and August 1969 (Heath, 1975). The temporal variation probably arises from seasonal variation in river discharge and land drainage, and spatial variation may arise from entrainment of river discharge into specific areas (Garner, 1953, 1961).

2.2 RIG (*Mustelus lenticulatus*)

2.2.1 Taxonomy and Common Names

Rig are now taxonomically classified as *Mustelus lenticulatus* (Phillipps, 1932), although they have been called by a variety of other names such as *Emissola antarctica*, *Galeus antarcticus*, *Galeorhinus antarcticus* and *Mustelus antarcticus* in the past (Hector, 1872; Phillipps, 1924; Graham, 1956; Parrott, 1958; Whitley, 1968; Ritchie *et al.*, 1975). Until very recently, the latter of these terms was in most frequent use, even though the species was reclassified five decades ago. All contemporary literature cites the specific name as *lenticulatus* however, as it is now accepted that the species is distinct from *M. antarcticus* (Heemstra, 1973 *in* Francis, 1979). Past New Zealand references to *M. antarcticus* are therefore assumed to apply to *M. lenticulatus* (Francis, 1979).

There is probably no other species in New Zealand with more common names than rig. Smooth-hound, spotted smooth-hound, smooth dogfish, spotted estuary dogfish, gummy, spotted gummy shark, pioke, koinga and manga are just some of the names that this species has been known by at one time or another (Phillipps, 1924, 1947; Graham, 1956; Parrott, 1958; Heath and Moreland, 1967; Whitley, 1968; Anon, 1979). Various trade names such as lemonfish, silver strip and flake have also been adopted to overcome the marketing problems mentioned previously (Sorenson, 1970). This proliferation of names has caused a great many problems for the MAF staff who analyse commercial catch return forms.

To overcome these problems, the Ministry developed a list of standard common names for commercial fish species in 1979. This list gave the common name of *M. lenticulatus* as "rig" (Anon, 1979) and thus it has been referred to as such in this study.

2.2.2 Biology

Sharks of the genus *Mustelus* are found throughout the temperate waters of the world (Francis and Mace, 1980). They are typically small (less than 2 m), harmless sharks with a very tasty flesh.

The New Zealand species, *M. lenticulatus*, is a greyish brown colour along the dorsal surface, fading to dirty white below the lateral line. It has numerous circular white spots on the upper half of its body and, unlike our two common dogfish species, lacks spines on its two large dorsal fins (Phillipps, 1949; Graham, 1956; Heath, 1963; Moreland, 1963; Heath and Moreland, 1968). The head is flattened slightly and its small pavement-like teeth make it readily distinguishable from other school sharks (Parrott, 1958). It feeds mainly on crustaceans, echiurans, molluscs and worms, but may also eat lesser quantities of priapulids and small fish (Graham, 1956; King and Clark, in prep.). The wide range and variable size of prey species indicate that rig feed opportunistically (King and Clark, in prep.).

Rig are one of several ovoviparous breeders in the genus *Mustelus*. Fertilisation is internal and the embryos develop within two uteri (Francis and Mace, 1980). These embryos are nourished by the yolk sac and probably by absorption of organic material and water from the uterine fluid as in other *Mustelus* species (Ranzi, 1934 *in* Francis and Mace, 1980). Each embryo develops within a separate uterine membrane and after an approximate 11 month gestation period, the young are born during the spring and summer months at a total length of 30-32 cm (Parker, 1883a; Parker and Liversidge, 1890; Graham, 1956; Francis, 1979; Francis and Mace, 1980). After the birth of a litter, copulation and ovulation of a new set of eggs follow quickly, this being made possible by the fact that eggs are actually growing in the ovary while the embryos are still developing in the uteri (Graham, 1956; Francis and Mace, 1980).

Rig are found around the entire coast of New Zealand, but they are now most abundant between 39°S and 46°S (Mace, 1981). Their abundance shows marked seasonal fluctuations however, as the species is migratory. Their migratory pattern is very similar to that of many other shark species as described by Springer (1967). In the spring there is a rapid increase in rig numbers on the continental shelf as the fish begin migrating into shallower water to give birth to their young and mate again (Mace, 1979; Francis and Mace, 1980). Sexual segregation appears to be a feature of these migrations as there are notable changes in the abundance of males and females in local areas during this period (Francis and Mace, 1980; Mace, 1981). After mating they usually move further inshore and remain there for some time before returning to deeper water in the autumn. Graham (1956) notes that rig were caught on groper lines on the continental slope in 160 m or more during the winter, but their range also extends beyond the continental slope, as they have been reported from depths of up to 500 m (Francis and Mace, 1980).

The migratory behaviour of rig is still poorly understood. Detailed studies in the Tasman Bay - Golden Bay region showed that birth occurs outside the bay during October and November with mating probably following soon after in the deeper waters of the Bay (Francis and Mace, 1980; Mace, 1981). Mace (1981) suggested that the subsequent inshore movements may represent feeding migrations. A recent study by King (in prep.) has shown that this is not a satisfactory explanation, however. Females did not feed any more intensively on these grounds than in any other areas of the bay and they actually lost condition rapidly in these shallow waters. Thus at present, the reasons for further inshore migration after birth and mating are obscure.

Recent tagging work has shown that rig also migrate along the coast (Mace, 1979; Francis, 1983a). In some instances this migration is considerable. Of the 131 tagged fish recaptured to date, 29 (22.1%) had moved more than 100 nautical miles (nm) from the tagging site, and one fish had moved 372 nm (Francis, 1983a).

2.2.3 Recent Research

Although the early literature presents a reasonable body of general information describing the feeding habits, reproductive behaviour and migratory patterns of this species, there was very little information of a specific nature available until recently. With the exception of

Graham's work (1956), past references are based on observation rather than detailed analysis and are, therefore, prone to generalisation. Such generalisations are of very limited use for managing the species.

It was not until 1979 that a detailed study was undertaken to establish a biological basis for managing the species. This study (Francis, 1979) examined such things as size at maturity, embryonic growth rates and fecundity for the Kaikoura rig fishery. These parameters have now been studied in other rig fisheries as well (Francis and Mace, 1980). King and Clark (in prep.) have recently completed a more detailed study of the feeding habits of rig and the changes in female condition which are associated with inshore migration. At present, there are tagging experiments under way to determine exploitation rates of the species. This work has also provided information on stock boundaries and migratory routes.

The main aims of current research are to: estimate fishing mortality rates and stock size; estimate growth rates and therefore age at maturity and age-specific fecundity; examine catch rate trends, and to examine catch composition by size and sex (M. Francis, pers. comm.).

2.3 THE COMMERCIAL ENTERPRISE

2.3.1 Introduction

The Pegasus Bay rig fishery is one of the major rig fisheries in New Zealand. In its peak year (1977), it was the most important rig fishery of all, yielding 10% of the total rig catch (MAF, unpubl. data). Landings have declined since 1977, but it continues to make an important contribution to the national rig catch. In 1982 it yielded 6.4% of the total New Zealand rig landings (MAF, unpubl. data).

It is also an important fishery for the region. Rig do not constitute a large part of the Lyttelton landings, but they accounted for 16% of the total value of the port's fish landings (non-wetfish included) in 1981 (MAF, unpubl. data). In the past, this figure has been as high as 28%. The species is therefore, an important source of income for many of the local fishermen. It is particularly important to the set net fishermen, as many of these fishermen obtain the bulk of their summer income from rig.

The fishery is best described as a seasonal set net fishery. While the trawl contribution is significant (see Figure 2.4), trawlermen do not actively pursue the species. They take rig as a by-catch. Set net fishermen, however, target fish for the species during the summer months when the fish are concentrated on the continental shelf. There is some variation between years, but most target fishing occurs between October and March, with peak catches usually being taken in December (see Figure 2.2).

2.3.2 History of the Fishery

Although rig have been taken in Pegasus Bay for many years, there was no significant rig fishery in the area until the mid 1970s. One or two set net fishermen did sometimes target fish for rig during the 1960s, and trawlers may have occasionally target fished for rig if catches of other species were low, but it is unlikely that much target fishing for rig occurred before the early 1970s (A. Coakley, pers. comm.). Most rig was taken as a trawl by-catch as trawling was the dominant fishing method in the area. It was an important by-catch, however, particularly in the elephant fish fishery. Landings generally increased, therefore, (see Figure 2.3) along with the total Lyttelton wetfish catch. The only sustained drop in landings between 1960 and the early 1970s occurred between 1967 and 1969 when many Lyttelton vessels left the port to join the Chatham Island rock lobster boom.

It is not certain when set net fishermen first began to target fish for rig during the 1970s, but it was probably around 1973 or 1974 as the fishery grew from the demise of the elephant fish fishery. This was also a summer fishery and formerly one of major importance along much of the Canterbury coast. It was primarily a trawl fishery, however, as relatively few fishermen were set netting in Pegasus Bay prior to the development of the rig fishery. Coakley (1971) notes that during the period 1960-69, there were never more than six set net fishermen operating in Pegasus Bay. The initial transition to rig fishing was made, therefore, by a small number of fishermen. Numbers remained low for some time after the transition and the pattern of fishing changed little as the fishermen continued to fish in the shallow areas closed to trawling.

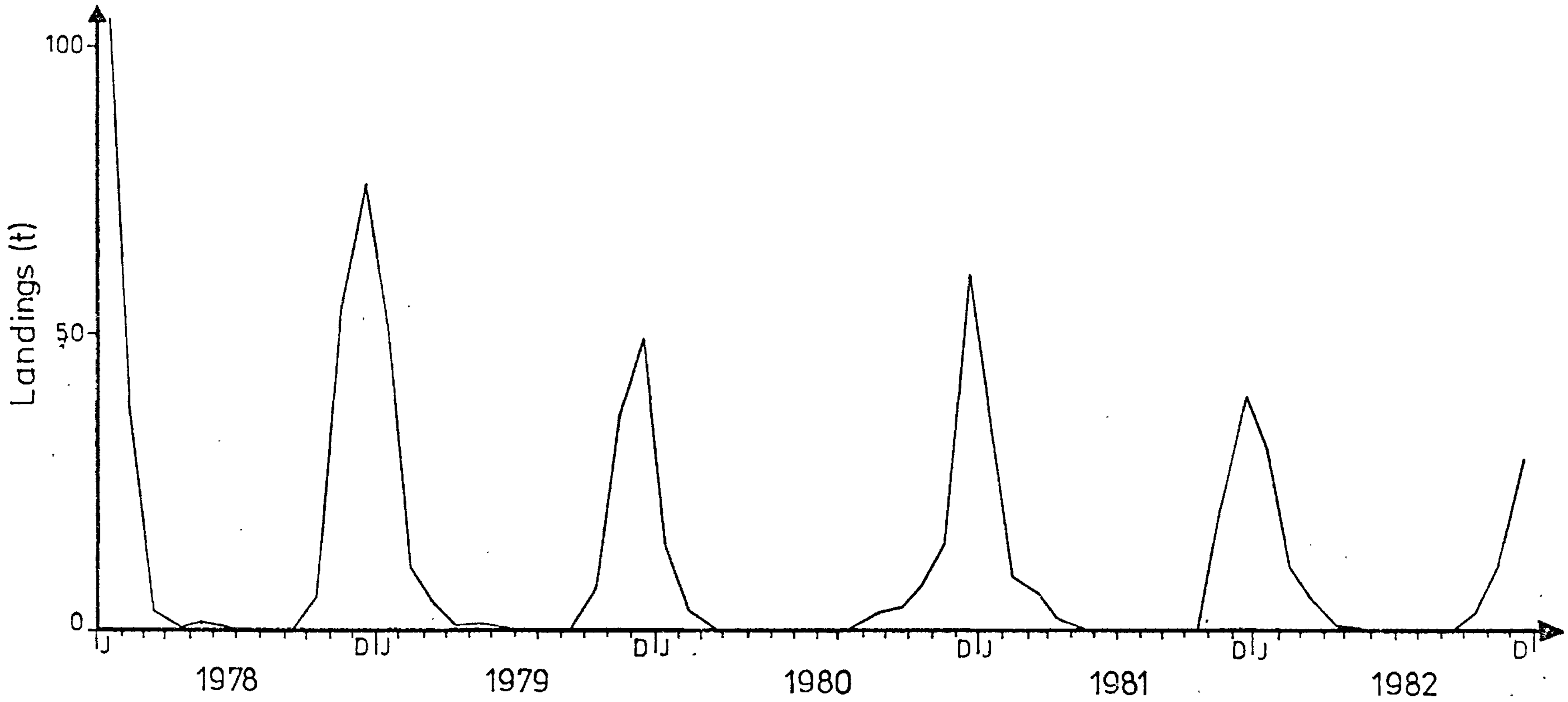

Figure 2.2 Monthly set net rig landings at Lyttelton, 1974-1982. Includes landings at all small ports around Pegasus Bay, e.g. Motunau, Sumner. Landings of set net vessels fishing less than 350 metres of net are not included. (Source: MAF, unpubl. data).

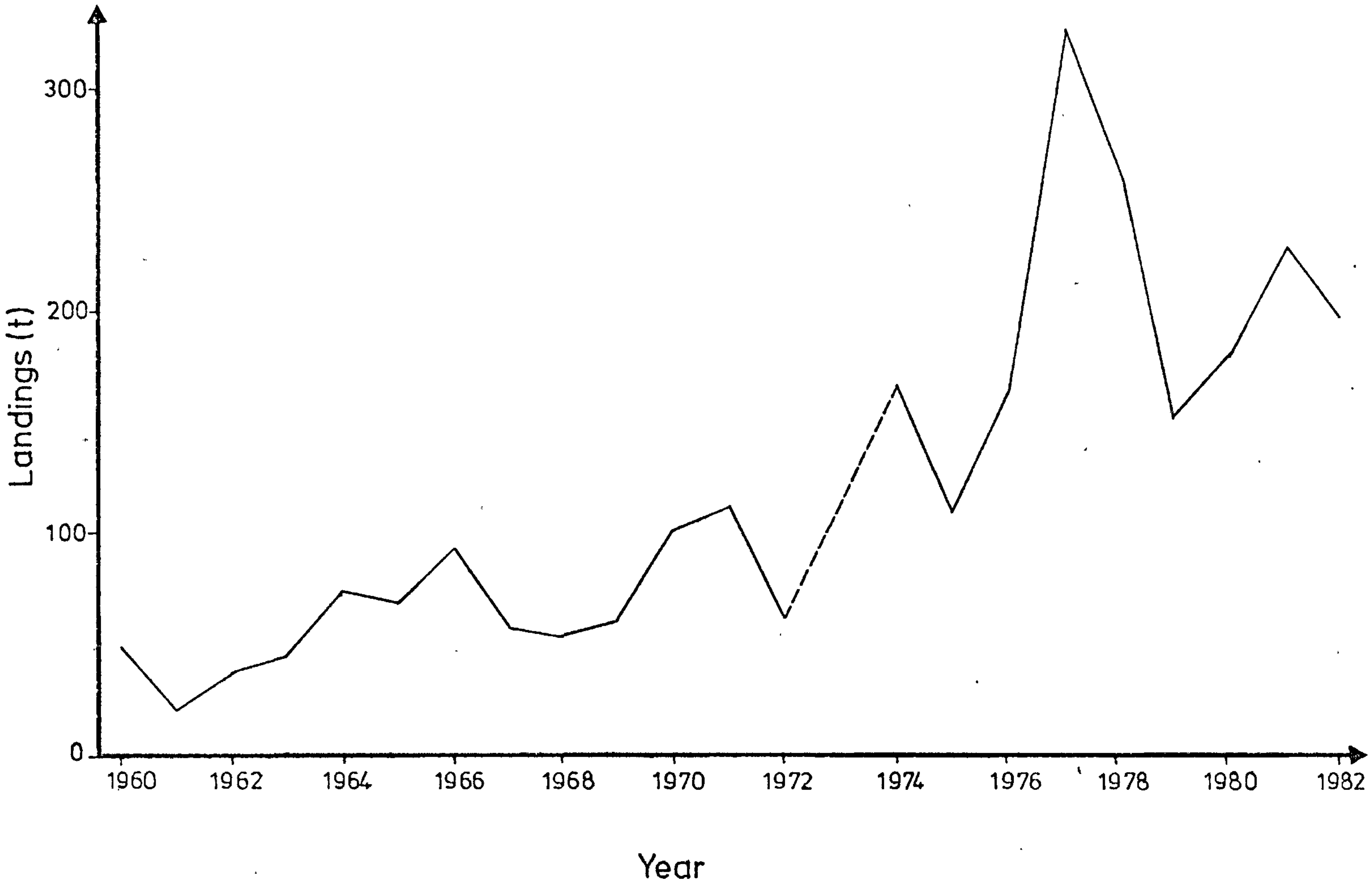

Figure 2.3 Lyttelton pioke landings, 1960-1982. Includes landings at all small ports around Pegasus Bay. (Source: Ritchie *et al.*, 1975; MAF, unpubl. data).

Although the set net rig catch was still low in the 1975-76 and 1976-77 seasons, set netting was gathering considerable momentum. While the mean number of set net vessels fishing each month was the same in both seasons, the mean number of days fished each month by these vessels nearly doubled[1] (see Figure 3.5). With good catches being made during the later months of the 1976-77 season, the fishery seemed poised for further expansion.

The magnitude of the changes which did occur was probably unexpected. Set net activity increased dramatically in the 1977-78 season as many new vessels joined the fleet. The mean number of vessels set netting for rig each month during this season was more than three times that of the previous season[1] (see Figure 3.2).

The most likely stimulants to the expansion of the set net fleet at this time are: increased catches by the set net vessels in the 1976-77 season; a large increase in the price obtained for rig (see Figure 2.5); the introduction of monofilament nylon nets, and the introduction of mechanical net hauling equipment. The latter may be of somewhat lesser importance, however, as many vessels that were fishing at this time did not have this equipment (C. Hill, W. Matthews, J. Waller, pers. comm.).

Unfortunately, no seasonal year data are available for trawlers. It may be seen from Figure 2.4, however, that despite the sharp increase in set net rig landings in 1977, trawling was still the dominant method of rig capture. Recorded trawl rig landings also rose considerably in 1977 and so it is possible that some trawlers may have spent time target fishing for rig during 1977. It is unlikely that this has occurred to any significant extent since 1977. Trawl rig landings dropped greatly in 1978 and so with a further increase in the set net rig catch, set netting displaced trawling as the dominant method of rig capture. Set netting has remained the most important method of rig capture in this fishery ever since.

Set net and trawl landings have both shown considerable variation since 1977, but overall they have declined. Some of the variation in the set net catch is attributable to changes in the amount of fishing

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[1] These figures are only for the October-January period in each season and only for vessels fishing more than 350 m of net.

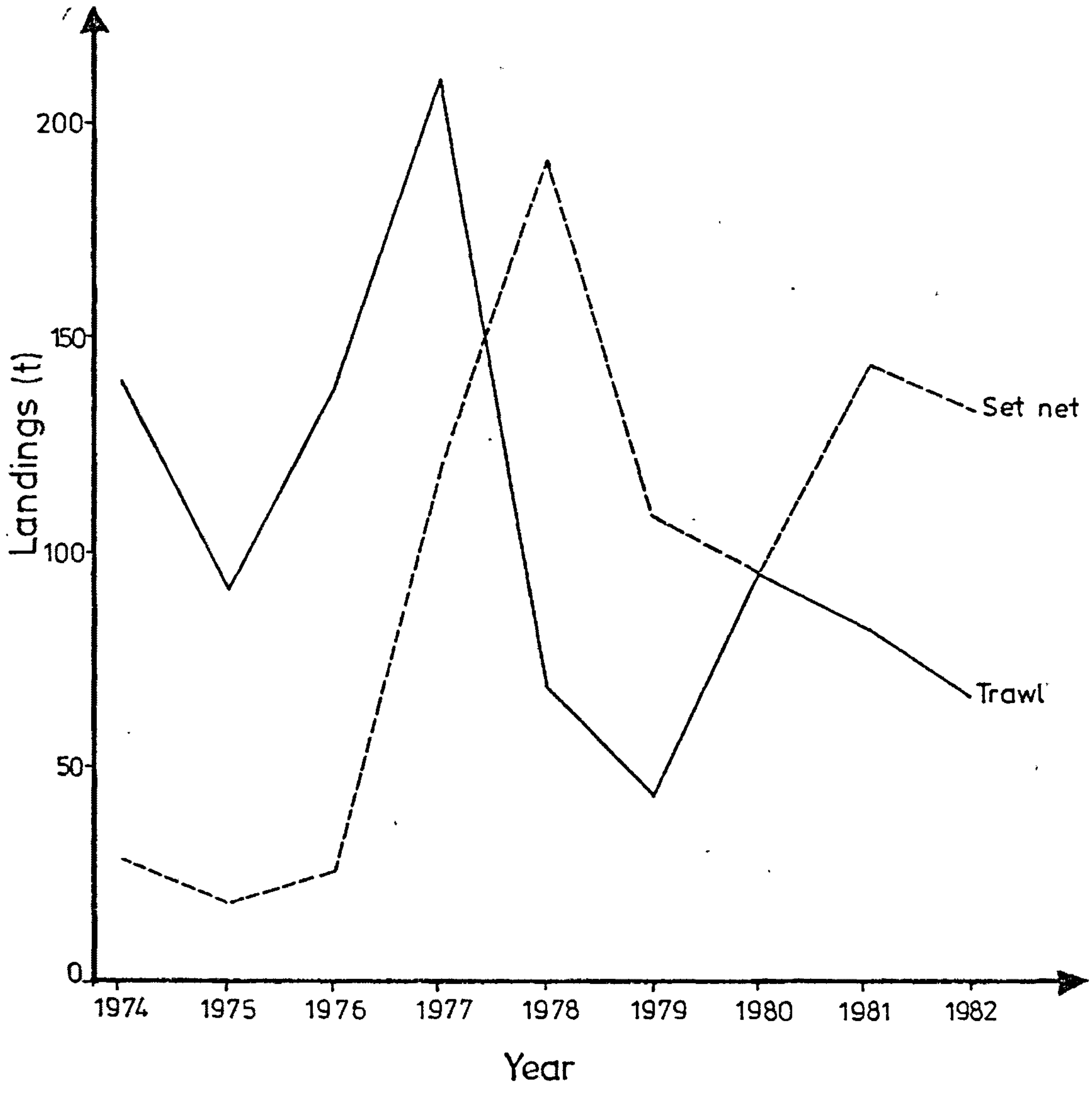

Figure 2.4 Trawl and set net landings at Lyttelton, 1974-1982. Includes landings at all small ports around Pegasus Bay. (Source: MAF, unpubl. data).

Figure 2.5 Real changes in port price of rig, 1973-1983. Original port price data are adjusted using the fish price index shown in Anon (1983). (Source of original data: NZFIB, unpubl. data).

effort, but some is also due to falling catch rates (see section 3.3.3). The drop in trawl landings would seem to be a result of a fall in catch rates, as trawling effort does not appear to have decreased in Pegasus Bay since 1977.

As the catch rates began to decline, so too did the set net fishermen's profits. Profits were further depressed by rising costs and a real decline in the unit price paid to fishermen for rig (see Figure 2.5). Consequently, the fishery experienced some very significant changes.

The most obvious of these changes was a reduction in the number of rig fishermen. The largest reduction occurred between the 1978-79 and 1980-81 seasons, when the mean number of set net vessels fishing each month in the October - January period (and fishing more than 350 m of net) fell from 24.2 to 12.8 (see Figure 3.5). Vessel numbers have more or less stabilised since this time. The mean number of vessels fishing for rig each month in the October - January period has only shown a very slight decline over the last three seasons (see Figure 3.5). This does not mean that the fleet is the same now as it was three years ago, as it is not. It simply means that the number of entrants has been roughly balanced by the number of withdrawals since 1980-81.

Decreasing profits also caused changes in the way that the fishing operations were run. As the catch rates fell, fishermen began to set more net in an attempt to maintain their catches. The mean length of net used by each operator has increased by approximately 200 m per year since 1977-78 (see Figure 3.4). There has also been a trend towards using smaller mesh sizes. Data collected during the 1979-80 season show that most fishermen used 178 mm mesh nets, but that a number used 191 mm and 185 mm mesh nets. Very little 165 mm mesh was in use. Most fishermen still use 178 mm mesh nets, but 165 mm mesh is now quite common as well. Nets with mesh sizes larger than 178 mm are now rare.

The other important behavioural change which has occurred as catch rates have declined, is a change in where the fishermen set their gear. When the fishery first developed, most fishermen were setting their nets in the shallow trawl-prohibited areas near to the coast. By the 1979-80 season, most fishermen were setting in 15-25 m of water. Some were fishing in 10-12 m and very occasionally nets were set in 35-40 m.

Now, most set net fishing occurs in 35-40 m of water. A small amount occurs out in "the weed" at a depth of approximately 70 m, and the largest boats regularly fish on the continental slope in the Pegasus Canyon. Very little fishing occurs in waters less than 25 m deep. Since the bay has a relatively gentle slope, the fishermen have to travel much greater distances to fish in these deeper waters. This has increased fishing costs considerably, as fuel is a major running expense.

2.3.3 The Fishery in 1982-83

Most of the information which follows, was collected through a survey of Pegasus Bay set net fishermen (see section 5.2). The aim of the survey was to describe the fishery as it existed in the 1982-83 season. Some changes have occurred since the season finished (e.g., some fishermen have changed their fishing practices and some have retired from fishing). The most significant difference between the fishery in 1982-83 and 1983-84, is that most "Group C" fishermen have been excluded from the fishery (subject to appeal) as a result of the first decision in the effort reduction process (see section 1.1).

Due to the limited time available, the trawl fleet has not been examined in detail in this study. Because trawlers do not target fish for rig, it was thought that attention should be focused on the set net fleet.

A. Participation in the fishery

The set net fishermen who participated in the fishery during the 1982-83 season, were a very diverse group. There was considerable variation between fishermen with respect to the size and economic importance of their operations and the way that the operations were run. These differences were largely the result of different motives for being involved in the fishery.

For the purposes of this study, the set net fishermen have been separated into three groups: the full-time fishermen who target fish for rig in the summer (Group A); the part-time fishermen who fish seriously during the rig season but do not fish outside this season (Group B); and "the rest" (Group C).

Group A was the smallest group, containing only five vessels. All fishermen in this group set netted for rig in the summer months, but reverted to either trawling or dredging for the rest of the year. The vessels were all owner-operated. Two were run on a partnership basis, with both partners working on the vessel, while the other three had only one owner. All vessels were worked by two fishermen. The vessel owners had a mean of approximately 12 years commercial fishing experience.

Three of the five vessels were operated in a quite different manner to the other vessels in the fleet. These three vessels remained at sea with their nets for periods of 2-4 days, lifting and re-setting them approximately every 12 hours. At the end of a fishing trip, the nets were brought back to shore. These fishermen typically fished much further out than the other set net fishermen. They often fished 60-80 km from port, this being made possible by the large size of the vessels and the fact that they were not returning to port each night. The remaining two vessels in this group were operated in a similar manner to Group B vessels as described below.

Group B contained 10 vessels. All but one of these vessels were owner-operated. Two of the owner-operated vessels were owned on a partnership basis, but the rest had only one owner. As with the previous group, all vessels were worked by two fishermen.

These vessels were only worked seasonally. The owners relied mainly, or in some cases solely, on fishing for an income during the rig season, but outside the rig season they did not fish. Most were tradesmen (e.g., plumbers, bricklayers) in the off-season, but other occupations included shop proprietor and unskilled labourer. Most crew members were also tradesmen or labourers in the off-season. The fishing experience of the vessel owners was extremely varied for this group, ranging from one to 20 years. The mean was approximately 10 years.

The fishermen in this group only made one-day excursions. They cleared their nets and then re-set them before returning to the shore. Fishing was most commonly carried out 25-35 km from port.

Group C contained all those set net fishermen who do not fall into one of the first two categories. This included the 'low-key' rig fishermen who only set netted for rig occasionally and the set net fishermen who did not target fish for rig. It contained 14 vessels, all of which were owner-operated. In many cases, the skipper worked alone on these vessels.

The fishermen who did target fish for rig, generally used modest amounts of net and they did not usually venture far offshore. The operation was treated as a means of supplementing the income from another full-time occupation.

Most of the fishermen in Group C did not fish specifically for rig. They generally fished for a range of species, either inside Lyttelton Harbour, or close inshore along the beach. Two of these fishermen were full-time commercial fishermen, but the rest did not regard their operation as a financial enterprise. For most, fishing was simply a weekend or retirement activity that was carried out for pleasure. As a result, only very small amounts of net were used (the mean was approximately 200 m). Furthermore, very little of the fish which these fishermen caught was sold. Most of it was either kept for personal consumption or given away. In some cases, it was traded for farm produce.

B. Fleet structure

The Pegasus Bay set net fleet was very diverse with respect to vessel size and design. Although the differences between groups were large, the vessels within each group shared many common characteristics.

On the whole, group A vessels were the largest. They ranged from 8.5 m to 13.2 m in length, the mean being 10.5 m. They all had displacement hulls made from either kauri or plywood. Engine size was variable, but most vessels had a cruising speed of 7-8 knots. Both the hulls and engines were old in most cases; the hulls ranged from 11 to 40 years old and the engines from one to 13 years old.

Group B vessels were small high-speed vessels, built specifically for set netting. They all had fibreglass or fibreglass-on-ply planing hulls, ranging from 6.0 m to 8.4 m in length. The mean length was 7.1 m. Most of the hulls were very new. The mean age was only 3.7 years.

Nearly all of these vessels were propelled by large stern-drive or outboard engines. These engines were typically between 250 and 450 horse-

Table 2.1 Description of Pegasus Bay set net fleet in 1982-83[a].

	Group		
	A	B	C
NUMBER OF OPERATIONS	5	10	15
SIZE OF SAMPLE	4	9	11
OWNERSHIP			
- Number of sole owner-operators	2	6	11
- Number of partnership owner-operators	2	2	-
COMMERCIAL FISHING EXPERIENCE OF SKIPPERS (yrs)			
- Mean	11.8	10.6	14.0
- St. dev.	5.5	6.6	14.9
OFF-SEASON OCCUPATIONS OF SKIPPERS AND CREW MEMBERS	All full-time fishermen	Mostly tradesmen or labourers	Variable
MEAN NUMBER OF CREW MEMBERS (INCLUDING SKIPPER)	2.0	2.0	1.3
VESSEL CHARACTERISTICS			
(a) Hull			
(i) Length (m)			
- Mean	10.5	7.1	5.9
- St. dev.	1.7	1.0	1.1
(ii) Age (yrs)			
- Mean	19.4	3.7	14.4
- St. dev.	12.0	1.8	13.0
(b) Engine			
(i) Horsepower			
- Mean	147.0	337.0	52.8
- St. dev.	86.2	108.1	45.1
(ii) Age (yrs)			
- Mean	7.8	2.1	7.3
- St. dev.	5.4	1.3	5.8

[a] Does not include set net vessels which did not land rig in the 1982-83 season.

power (hp). Consequently, cruising speeds were in the order of 20-30 knots. Since the engines rev at very high rates, they have a short lifespan, e.g., 3-5 years for outboards. The mean age of the engines was, therefore, very low (two years).

Group C vessels were much more variable than either of the other two groups and so it is difficult to identify any distinguishing characteristics of the group. The vessels had wood, aluminium or fibreglass-on-ply hulls, ranging from 3-80 years old. Most were driven by inboard engines, but a few had outboards. The engines also ranged from the very new to the very old. Overall, however, the vessels were smaller and the engines less powerful than the vessels in either of the other two groups. The hulls ranged from 4.3 m to 9.2 m in length, with the mean being 5.9 m. Most engines were between 20 and 70 hp.

C. Marketing

Fish marketing is very complex in Christchurch, as two different types of marketing system are in operation. One is an auction system, the other an agency system.

Most of the fish sold in Christchurch is sold under the auction system. The two wholesaling and processing companies which handle most of the fish, Feron Seafoods Ltd. and United Fisheries Ltd., both operate a daily auction. These companies accept fish from any vessel and sell the fish in its landed state to retailers (or occasionally wholesalers) on behalf of the fishermen. The fishermen are then paid the auction price, less a handling fee. Fish which is unsold at the auction or which does not fetch the floor price set by the auctioning company, is bought by the company for processing in its own plant. This system gives rise to considerable price variation. Prices vary according to the availability of fish, and so there may be considerable variation, even from one day to the next.

Wholesalers operating under the agency system, sell their fish to a regular clientele of retail outlets. Fishermen who sell fish to these wholesaling companies, are paid a fixed price for the fish. The price does vary throughout the season, but less erratically than with the other system.

Although there were large price variations during the season, the general trend in both systems was for higher prices to be paid at the beginning and end of the season, and lower prices to be paid during times of peak catch. Most fishermen were receiving between \$2.40/kg and \$2.60/kg for rig "trunks" during the height of the 1982-83 season. Before November and after February, prices were usually between \$3.00/kg and \$3.30/kg, but the price did go as high as \$3.70/kg (A. Coakley, pers. comm.).

The wholesaling and processing companies sell most of their rig to either retail or fast food outlets. Retailers sell rig fillet under the tradename "lemonfish". During monthly rounds of ten Christchurch retail outlets, I observed rig selling for between \$5.50/kg and \$7.00/kg. None of the shops showed very large price variations from one month to the next.

D. Summary

Although small, the Pegasus Bay rig fishery is very complex. There are complex interactions between the trawl and set net fleets, and within the set net fleet, there is considerable diversity with respect to the motives for fishing and the way that the operations are run.

The fishermen who participated in the fishery during the 1982-83 season are separated into three groups. Group A operators were full-time fishermen. They fished in other fisheries outside the rig season, and only set netted during the summer. Most of these fishermen remained at sea for several days each trip, lifting and resetting their nets at regular intervals. They brought their nets back to shore at the end of a fishing trip. Group B fishermen fished full-time, or nearly full-time, during the rig season, but did not fish outside this period. Most were self-employed tradesmen during the off-season. These fishermen returned to port each evening, but left their nets set in the bay. Most Group C fishermen were not fishing for financial gain during the 1982-83 season. Fishing was usually a recreational or retirement activity for these fishermen. Those that were fishing for financial gain, did not fish full-time during the rig season.

Port prices for rig, showed considerable variation throughout the season. Overall, however, they increased as supply diminished.

3.0 CATCH-EFFORT ANALYSIS

3.1 INTRODUCTION

Good catch and effort statistics are crucial for the successful management of any fishery. The reason for this is that they allow fishery scientists to assess the state of fish stocks.

The state of a fish stock is determined by two factors: population size and population structure. Although catch and effort statistics do not usually yield any information on population structure, they do provide information on the apparent abundance of fish, i.e., the abundance of fish in the exploited portion of a stock. This is very rarely the same as total stock abundance but it is nevertheless a vitally important quantity.

Apparent abundance (A) is mathematically defined by the expression

$$A = \frac{Y}{F} \qquad (3.1)$$

where Y = total catch, and
F = instantaneous fishing mortality rate (Rothschild, 1977)[1].

Since the instantaneous fishing mortality rate cannot be estimated from catch and effort statistics, it is assumed that fishing mortality is proportional to the amount of fishing effort (Beverton and Holt, 1957) according to the relationship,

$$F = q f \quad \text{(FAO, 1976)} \qquad (3.2)$$

where q = catchability coefficient, and
f = effective fishing intensity (FAO, 1976) or nominal fishing effort (Rothschild, 1977).

It follows that,

$$A = \frac{1}{q}\left(\frac{Y}{f}\right) \qquad (3.3)$$

---

[1] F is related to the proportion of fish dying due to fishing (P_F) by the expression,

$$P_F = \frac{F}{Z}\,(1 - e^{-Z})$$

where Z = total instantaneous mortality rate (Ricker, 1977).

The term Y/f is by definition the catch-per-unit-effort (CPUE) (Marr, 1951; Beverton and Parrish, 1956), and thus equation 3.3 may be restated,

$$A = \frac{1}{q}(CPUE) \quad \text{(FAO, 1976).} \tag{3.4}$$

Since CPUE is proportional to apparent abundance, CPUE may be used to monitor the apparent abundance of fish from year to year. In practice, CPUE is usually used to monitor total abundance, as it is usually assumed that apparent abundance is proportional to total abundance[1] (FAO, 1976). It is important to note, however, that CPUE is proportional to the *average* abundance of fish *while fishing is in progress* (Ricker, 1940).

It is also important to note that the relationship between CPUE and abundance only holds perfectly true when certain "ideal" conditions are met. For seasonal fisheries, these conditions are that:

(i) the commercially useful portion of a fish stock is fished with equal intensity in every part of the population's geographical range;

(ii) the same amount of effort is applied in the fishery throughout the fishing season;

(iii) the catching efficiency (and therefore the catchability coefficient) of the fishery remains constant throughout the period examined; and

(iv) that natural mortality within the population during the fishing season is balanced by natural increase (growth and recruitment) during the same period (Ricker, 1940).

Clearly, these conditions will never be completely satisfied. Providing any departures from the ideal state are not too serious, however, then CPUE will still be a useful index of abundance.

Catch and effort statistics can also be used to estimate a fish stock's sustainable yield. Two types of models are used for these purposes: stock production models (e.g., Schaefer surplus production model) and dynamic pool models (e.g., Beverton and Holt yield-per-recruit model). Stock production models are highly simplified models as they do

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[1] Total abundance is hereafter referred to as abundance.

not distinguish between growth, recruitment and natural mortality. The production resulting from these three processes is, therefore, treated as a single function of population size. Dynamic pool models are more sophisticated, as they do distinguish between these three processes.

One requirement of both types of models is catch and CPUE data for a large number of years. Since the data used in the following analysis do not cover a long period of time, it is impossible to apply either type of model to estimate the sustainable yield. The catch and effort data can only be used, therefore, to assess changes in the abundance of rig in the Pegasus Bay region throughout the history of the fishery. This is still expected to provide a good indication of the present biological status of the fishery. Since rig caught in this region are part of a wide-ranging stock which is also exploited by several other fisheries, data from other regions are also discussed briefly to aid interpretation.

3.2 COMPUTING CATCH-PER-UNIT-EFFORT INDICES

CPUE indices are only ever as good as the data from which they are calculated. Thus, both the catch and effort data must be accurate if CPUE is to be an unbiased indicator of abundance.

3.2.1 Catch Data

There are two general problems with catch data in this respect. The first is that the quantity of fish which is landed, is rarely the same as that which dies as a result of the fishing operation. Some fish which are caught by the nets drop out, either while the net is still set or while it is being hauled. Some of these fish may die later as a result of the injuries sustained while in the net. Predation and spoilage may also claim substantial but unrecorded quantities of fish. For low-value species, even good quality fish are frequently discarded. In these cases, landings will bear little relation to the actual catches.

The other problem with catch data is that fishermen frequently under-report their catches on the statistical return forms they submit to the MAF. Thus, even when fish is landed, it is not always recorded.

The overall result of these factors is that recorded "landings" underestimate true catches considerably. The extent of this bias is unknown and probably variable through time.

3.2.2 Effort Data

Fishing effort is defined as the mathematical product of fishing power (the fish catching capacity of a fishing unit) and fishing time (Beverton and Parrish, 1956; Gulland, 1956; Beverton and Holt, 1957). A suitable measure of effort must therefore account for both of these factors.

A. Factors affecting the fishing power of set net units

The fishing power of any form of static gear such as set nets, is mainly influenced by the characteristics of the gear itself. Vessel characteristics may be important, but usually only indirectly, e.g., they may determine where and how much gear can be fished.

The three major factors which influence the fishing power of set nets are considered to be the amount of net, the selectivity and efficiency of the net, and the skill of the fishermen.

(a) Amount of net

The most obvious factor affecting the fishing power of set nets is the amount of net in use. Providing the density of fish does not decline over the range of any increase, then as the amount of net increases there is a proportional increase in the chance that a fish will encounter the net. If all other things are equal, then the chance of catching a fish also increases proportionately. Thus, so long as adjacent nets are not competing for the same fish at the same point in time, it is generally assumed that fishing power increases in proportion to the amount of gear in use (Ricker, 1940).

The amount of net is a function of both the length and depth of the net. The depth of a net is usually of lesser importance than the length in bottom set net fisheries, however, as many demersal species have narrow vertical distributions above the seabed. Once the distributional range of the target species is fully fished, the power with which a net fishes for the target species will not be increased with further increases in the depth of net, simply because the fish do not occur in the additional region being fished.

The density of fish may also decline over the range of any increase in net length. Ricker (1940) points out that when additional gear is used, it may occupy less favourable fishing grounds, in which case fishing power is not increased in proportion to the extra net. This may be expected to occur where a fish is highly selective with respect to habitat requirements, where it has a very concentrated distribution, or where any combination of these factors exists. The effect would be difficult to detect without detailed information on the distribution and movements of fish and the catch rates in various localities, however. In most situations it can probably be assumed that an increase in the length of net will result in a proportional increase in fishing power. Length of net is likely to be the most important component of fishing power for set nets (FAO, 1976).

(b) Selectivity and efficiency of nets

Nets may be selective (and therefore relatively more or less efficient) with respect to many variables such as age, size, sex, condition, behaviour and habitat (Hamley, 1975), but the term is used in its traditional sense here, meaning selection by size.

The selectivity and efficiency of set nets is influenced by an enormous number of net characteristics. These characteristics have recently been comprehensively reviewed by Hamley (1975) and von Brandt (1975). Some of them will be mentioned briefly here, however, to explain how they affect fishing power.

(i) Mesh size. The catching efficiency of a net of any particular mesh size, varies with the size of fish. The fishing power of any given mesh size depends, therefore, upon the size structure of the population. Since fishing decreases the average age, and hence size, of fish in a population, the mesh size producing the greatest efficiency will decline with time.

(ii) Mesh shape. Fish with narrow and high cross-sections are fished more effectively with mesh that is vertically stretched, while fish with flat cross-sections are fished more effectively with horizontally stretched mesh (Steinberg, 1964 *in* von Brandt, 1975). Thus, fishing power generally increases as mesh shape conforms more closely with the cross-sectional body shape of the target species.

(iii) Net material. If all other things are equal, then fishing power increases with decreasing visibility, increasing flexibility, and increasing elasticity of the mesh material (Atton, 1955; Hansen, 1974). Thus, fishing power may change if one material is substituted for another, or if the same material is made less visible, more elastic or more flexible. A good example of the effect of substituting one net material for another, was seen in New Zealand during the early 1970s when cotton and linen nets were replaced by nylon nets. Nylon's greater elasticity and reduced visibility more than compensated for the loss in flexibility with the result that fishing power was greatly increased. One means of making nets less visible, more elastic and more flexible is to decrease the diameter of the mesh material. Providing a reduction in mesh diameter does not weaken the material to the point where it will break under the strain of a struggling fish or hauling, then fishing power will be increased.

In addition to the above, there are several other factors which may also affect fishing power, e.g., the hanging coefficient of the net (the ratio of the length of completed net to the stretched length of the webbing used in it), the age of the net, the colour of the float and lead-lines, and the tension with which the net is set. Changes in these factors are considered to have a more minor impact on fishing power.

(c) Skill of the fishermen

Although the fishing power of a net is invariably quantified in physical terms, its power is also a function of certain human factors. These factors are collectively termed "skill". They refer to where, when and how the gear is deployed.

Skill is a difficult entity to quantify as it is a function of inherent individual qualities, learning and experience. Since it cannot usually be quantified, it is important to watch for any changes in the level of skill in a fishery. Any increase in the total skill in a fishery will alter the effective fishing effort and hence bias CPUE by overestimating abundance in recent years (FAO, 1976).

(d) Other factors affecting fishing power

The fishing power of a net can be drastically influenced by the capture of non-target species. If the net catches large quantities of non-target species, then the power with which the net fishes for the target species is severely reduced and CPUE will underestimate the target species' abundance. This may be an important consideration in fisheries where the by-catch is consistently high, but it is unlikely to be so if the by-catch is always or predominantly low.

Another factor which can bias estimates of fishing power in a multi-species fishery is a change in the fishermen's choice of target species. Choice will be mainly determined by the abundance of a species and its market price, either of which may change (FAO, 1976). If there is a shift in species preference then the relative proportions of fishing power which are directed towards each species may change. Where these changes go unnoticed in catch-effort analyses, CPUE will overestimate real declines in abundance of the former target species (FAO, 1976).

Environmental phenomena may also affect the fishing power of set nets. Currents can roll a net up, thereby reducing its effective fishing area (pers. obs.), or they can cause it to billow in a way which prevents proper gilling of the fish (Hickling, 1961 *in* von Brandt, 1975). In extreme cases the net may be swept away altogether. These currents may be either temporary or permanent. Where they are temporary they are unlikely to be important unless they are severe or unless they occur frequently.

B. The choice of fishing time units

If fishing effort is to be described accurately, then it is important to use an appropriate measure of fishing time in the effort calculations. It is not easy to describe such a measure for set nets, as catches do not always increase in proportion to the amount of time a net is in the water, i.e., fishing power often decreases with time (Kennedy, 1951; Beverton and Parrish, 1956; Beverton and Holt, 1957; Hamley, 1975). Kennedy (1951) states that,

"... *at very low levels of availability, doubling the interval between lifts will probably double the average catch (per lift),* *at moderate levels of availability a given number of nets will yield more if cleared daily than if cleared at longer intervals, and at high levels of availability nets can probably become saturated during the first day so that they will catch no more fish if they are left in the water for a longer time."*

At low abundance, therefore, the best measure of fishing time will be the number of days that the nets are fished. At high abundance, the best measure of fishing time will be the number of days that the nets are cleared. At moderate abundance, neither of these measures will be ideal.

Thus, it appears that different measures of fishing time are appropriate in different situations. What is appropriate for high abundance, is not appropriate for low abundance. This presents real problems in a fishery which is fished from high to low abundance, as it means that neither of these measures will accurately describe fishing time throughout the history of the fishery.

3.3 ANALYSIS OF THE PEGASUS BAY RIG FISHERY

The data used in this analysis were obtained from the monthly return forms which all commercial fishermen are required to submit to the MAF. Since these forms are confidential, the data were summarised for me by the MAF.

3.3.1 Assumptions

Before proceeding with the analysis, it is important to examine how well the data conform to the assumptions noted in section 3.1.

(i) *The commercially useful portion of a stock is fished with equal intensity in every part of the population's geographical range.*

CPUE will only be a valid index of abundance if the chance of any fish being caught is approximately the same as that of any other fish of a similar size and sex (Ricker, 1940).

The results obtained so far from the MAF rig research programme indicate that all rig around the South Island are part of one stock

(Francis, 1983a). While there is probably sufficient interchange between the east and west coasts of the South Island to maintain genetic links, the majority of the fish do not migrate from one coast to the other. For management purposes, therefore, the east and west coast fish can probably be treated as two stocks (M. Francis, pers. comm.). Even so, the distribution of effort over the east coast is far less than ideal with respect to the above assumption. Effort is markedly more intense near the fishing ports, and even within a fishery the effort is often concentrated into small areas.

This unequal distribution of fishing effort, is partly compensated for by the fact that rig are highly migratory. Of the 131 tagged fish which have been recaptured to date, 48% have travelled more than 20 nm from the tagging site, and 22% have travelled more than 100 nm within one season (Francis, 1983a). Thus, although the effort may not be uniformly spread, the probability of similar fish being caught may still be relatively constant throughout the population. It is considered, therefore, that the basic requirement relating to the chance of capture is met well enough to make the analysis valid.

(ii) *The same amount of effort is applied in the fishery throughout the fishing season.*

As with the previous assumption, there is a large difference between the observed and ideal situations. Ricker (1940) states, however, that,

> "*As long as the gear used at different times is more or less in the same proportion in successive years, this will probably not be an important source of error.*"

Figure 3.1 shows the proportion of the total seasonal October - January set net effort, which is applied in each of these four months for the period analysed. Although the proportion of effort applied in any one month does vary between seasons, it appears to be reasonably similar for most of the seasons examined. It is not expected, therefore, that any serious bias will result from this assumption.

(iii) *The catching efficiency of the fishery remains constant throughout the period examined.*

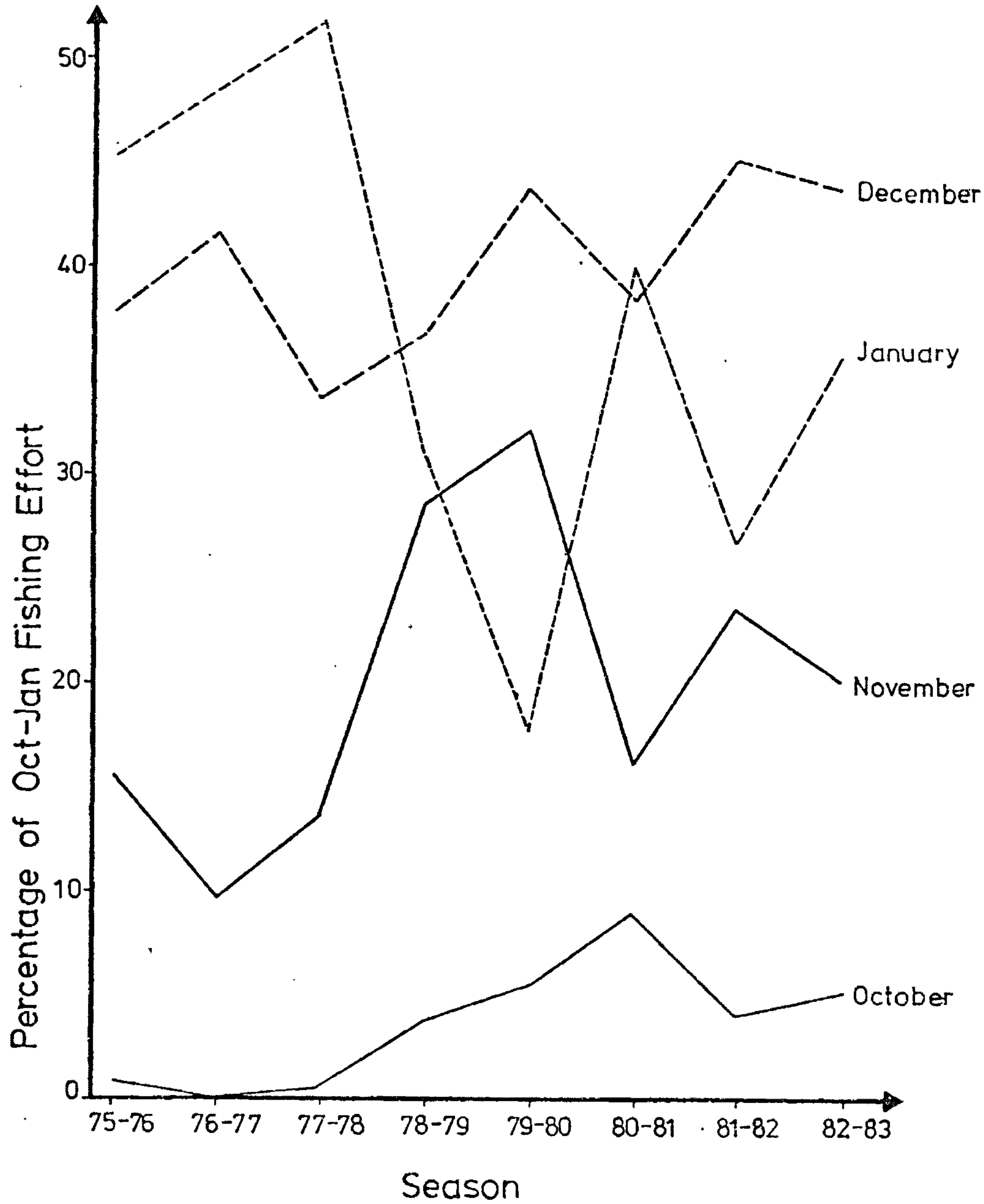

Figure 3.1 Percentage of seasonal set net fishing effort deployed in each month, 1975-1976 to 1982-1983. Values shown are percentages of the total October-January fishing effort deployed by set net vessels fishing in Pegasus Bay with more than 350 metres of net (Source: MAF, unpubl. data).

There are several factors which could produce changes in the efficiency with which the gear fishes for rig. These are environmental factors, interactions between nets, net saturation, technological improvements, and increases in the level of total fishing skill.

Environmental factors are considered to be a minimal source of error as any events which would affect the efficiency of the nets are unlikely to be frequent or prolonged. Any non-random events (e.g., north-westerly winds) will probably follow a fairly regular pattern of intra-seasonal variation from one year to the next, in which case biases will probably not be serious for the same reasons given in the previous assumption.

The effect of interactions between nets is a little more uncertain. Although it is unlikely to be an important consideration at present, it may have been in the past. During earlier years many of the boats were small. Since they were not able to fish far offshore, there could have been some crowding on the nearshore grounds. If this was the case, then abundance will be underestimated in these early years.

Of all the factors affecting catching efficiency, net saturation is probably the most significant. At present, rig catches are generally low and so saturation effects are probably only ever likely to occur with heavy by-catches of the spiny dogfish, *Squalus acanthias*. Although these large catches greatly inhibit the efficiency with which rig is caught, they are seldom made (R. Beggs, C. Hill, G. Sinclair, J. Waller, pers. comm.). Thus net saturation is not likely to be an important source of error at present. It may have been during the early years in the fishery, however, when rig catches were much greater. If the catches were large and frequent enough, then abundance would be underestimated in the earlier years.

Technological improvements and changes in the level of total fishing skill may also lead to biased estimates of abundance in this fishery. Some technological improvements have occurred, e.g., conversion to more efficient oval mesh (Francis and Smith, 1983), and fishermen's skill will have undoubtedly increased over the years. Both these effects will probably lead to an underestimation of abundance in the early years of the fishery.

Overall, therefore, this assumption may result in a significant underestimation of the abundance of fish in the earlier years of the period examined. This bias must be considered when interpreting the results of the analysis.

(iv) *Natural increases and decreases are balanced within the population during the fishing season.*

Unfortunately, it is not possible to assess the validity of this assumption as there is virtually no information available on growth, recruitment and natural mortality.

Since the data are only being used to reveal general trends in apparent abundance, it is concluded that the assumptions (with the exception of (iv) which is uncertain) hold well enough to make the catch-effort analysis valid.

3.3.2 Units of Measurement

Since the rig fishery is a summer fishery, the data are arranged into July-June years, so that all the months of one fishing season fall into the same period.

In the analysis which follows, only the October - January catch and effort data are used for each of the "years" examined. The reason for this is that some fishermen are known to target fish for other species when rig catches are low. This is most likely to occur outside of the October - January period. These four months have almost always yielded the highest catch rates and are, therefore, considered to be the most appropriate to analyse. Furthermore, they account for the greater part of the yearly set net catch and effort in each of the years examined (in all but one of the years examined, they account for more than 80% of the catch and more than 70% of the effort). Thus the CPUE index will be representative of a season but it will not describe the catch rate for the entire year.

Not all fishermen's catch and effort data are included in the analysis. First, only set net data are used. Appreciable quantities of rig have been caught by other methods at times (see Figure 2.4), but they were and still are usually only taken as a by-catch. This makes it impossible to determine appropriate effort units. The impact of these vessels on the abundance of rig is expected to be manifest in lower set net catch rates. Thus, set net catch rates should still be a reliable indicator of abundance.

Second, only set net fishermen who fished more than 350 m of net are included. Fishermen using less than this amount are probably "week-end" fishermen and they account for only a small proportion of both the catch and effort in each of the years. Although they do account for a slightly larger proportion of both catch and effort in earlier years, the difference is not thought to be significant and it is not expected to unduly bias the results.

All catch data used in this analysis are stated in kilograms "green"[1] weight. Since rig is "trunked"[2] before being landed, all landed weights must be multiplied by a factor of 2.0 to obtain the corresponding green weight (MAF, unpubl. data).

Effort data are stated in units of 100 m days. "Days" in this case refers to the number of days that fish were landed. This is not an ideal measure of fishing time, but it is the most reliable figure available, as it is the only measure that is consistently recorded (M. Francis, pers. comm.). It will correspond very closely with the number of days that the gear is lifted, as very few fishermen stay out at sea for more than one day. Thus, effort is calculated by multiplying the number of 100 m lengths of net each fisherman uses, by the number of days that he landed fish, and then summing the individual figures for all fishermen.

Although this measure does not account for many of the variables which affect fishing effort as discussed in section 3.2, it is the best measure available.

CPUE data are expressed in units of kg/100 m day. The seasonal CPUE index is calculated as the mean of all the individual monthly catch rates in the October - January period.

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[1] The "green" weight of a fish is its weight as it is taken from the sea.

[2] The "trunked" weight of a fish is its weight after the head, tail, fins and gut cavity contents have been removed.

3.3.3 Results

Figure 3.2 shows the total October - January set net catch and effort for all vessels fishing more than 350 m of net for the 1975-76 to 1982-83 seasons. The seasonal CPUE index for the same period is shown in Figure 3.3. The vertical lines about each point on the CPUE curve are approximate 95% confidence intervals of the means (i.e., mean ± (2 × standard error)).

Figure 3.4 shows the mean number of 100 m lengths of net fished by each fisherman and the total number of days fished by all set net fishermen who set more than 350 m of net in the period examined. The product of these two quantities is approximately equal to fishing effort. Once again the vertical lines show approximate 95% confidence intervals.

Figure 3.5 shows two components of fishing days; the mean number of set net vessels fishing per month and the mean number of days fished per month by each vessel. The latter of these terms is derived by calculating the mean number of days fished by each vessel in each month between October and January, and then taking the mean of all months and all vessels.

3.4 DISCUSSION

3.4.1 Catch, Effort and Catch-Per-Unit-Effort Trends

Although the period examined in the analysis is short, some very significant changes are evident in the catch, effort and CPUE.

Catch and effort were both low in the 1975-76 and 1976-77 seasons, as very few vessels were fishing in these two seasons (see Figure 3.5). The 1976-77 season differed from the previous season in one important respect, however; there was a considerable increase in the mean catch rate. Although individual catch rates varied widely, the mean catch rate was more than double that of the previous season. This was probably an important contributor to the events of the following season.

The 1977-78 season was a period of dramatic change in the fishery, as indicated by the catch curve. Many new vessels joined the fleet for this season and on average they fished more frequently than in previous seasons (see Figure 3.5). The result was that the total number of fishing

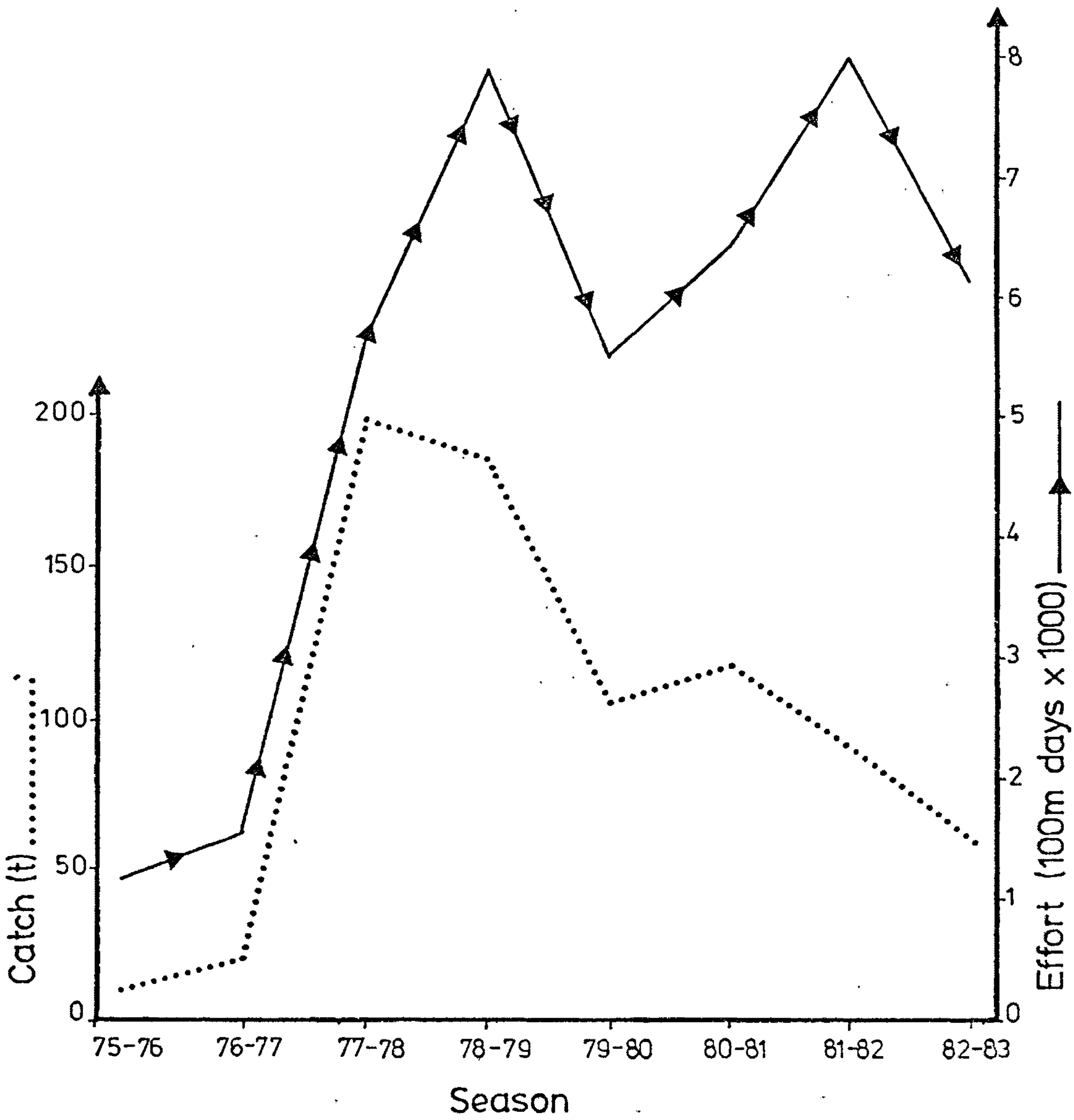

Figure 3.2 Rig catch and fishing effort of set net vessels fishing in Pegasus Bay, 1975-1976 to 1982-1983. Only the October-January catch and effort of vessels fishing more than 350 metres of net are shown (Source: MAF, unpubl. data).

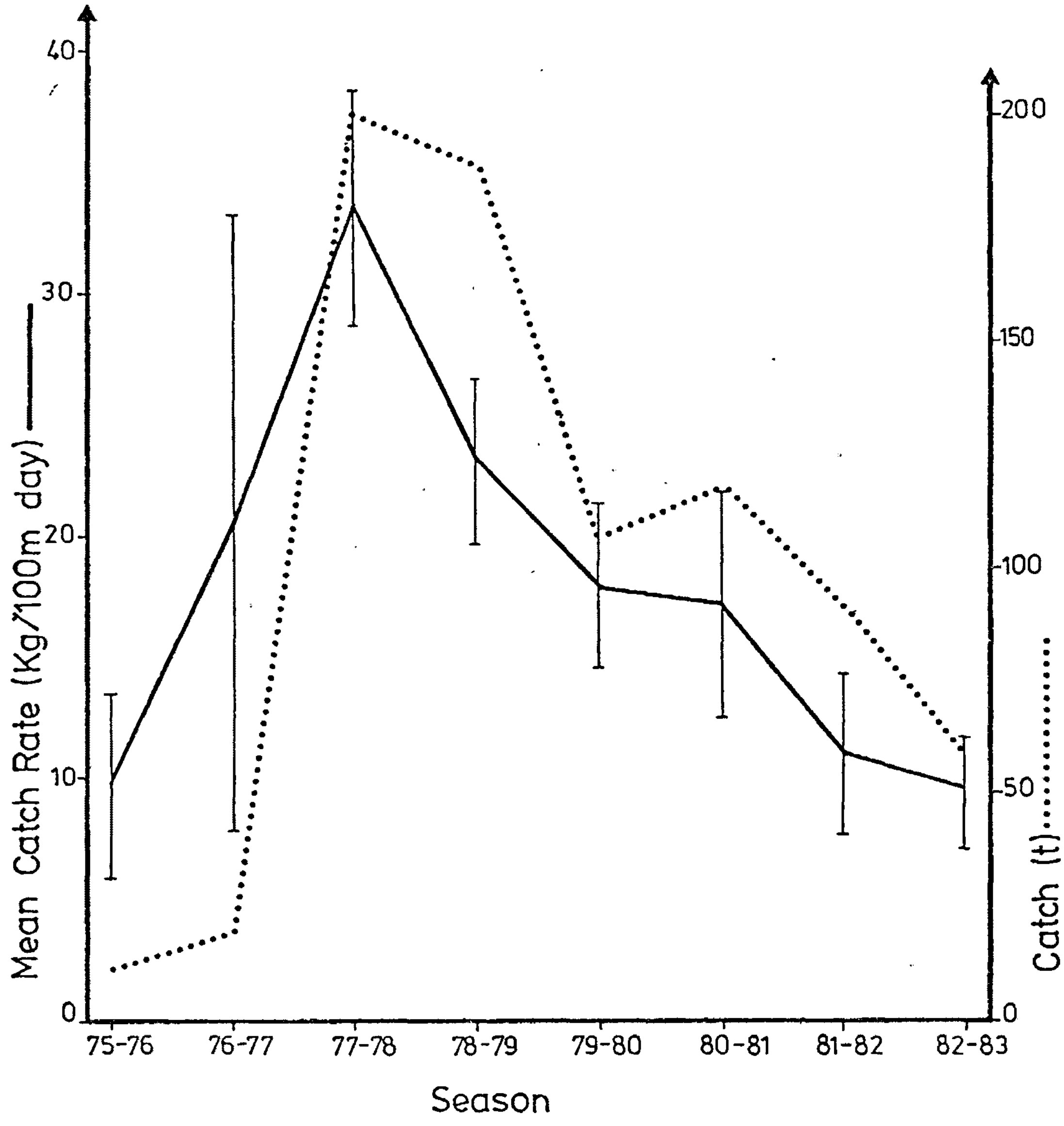

Figure 3.3 Mean catch rate of set net vessels fishing in Pegasus Bay, 1975-1976 to 1982-1983. Only the October-January rig catch and rig catch rate of vessels fishing more than 350 metres of net are shown (Source: MAF, unpubl. data).

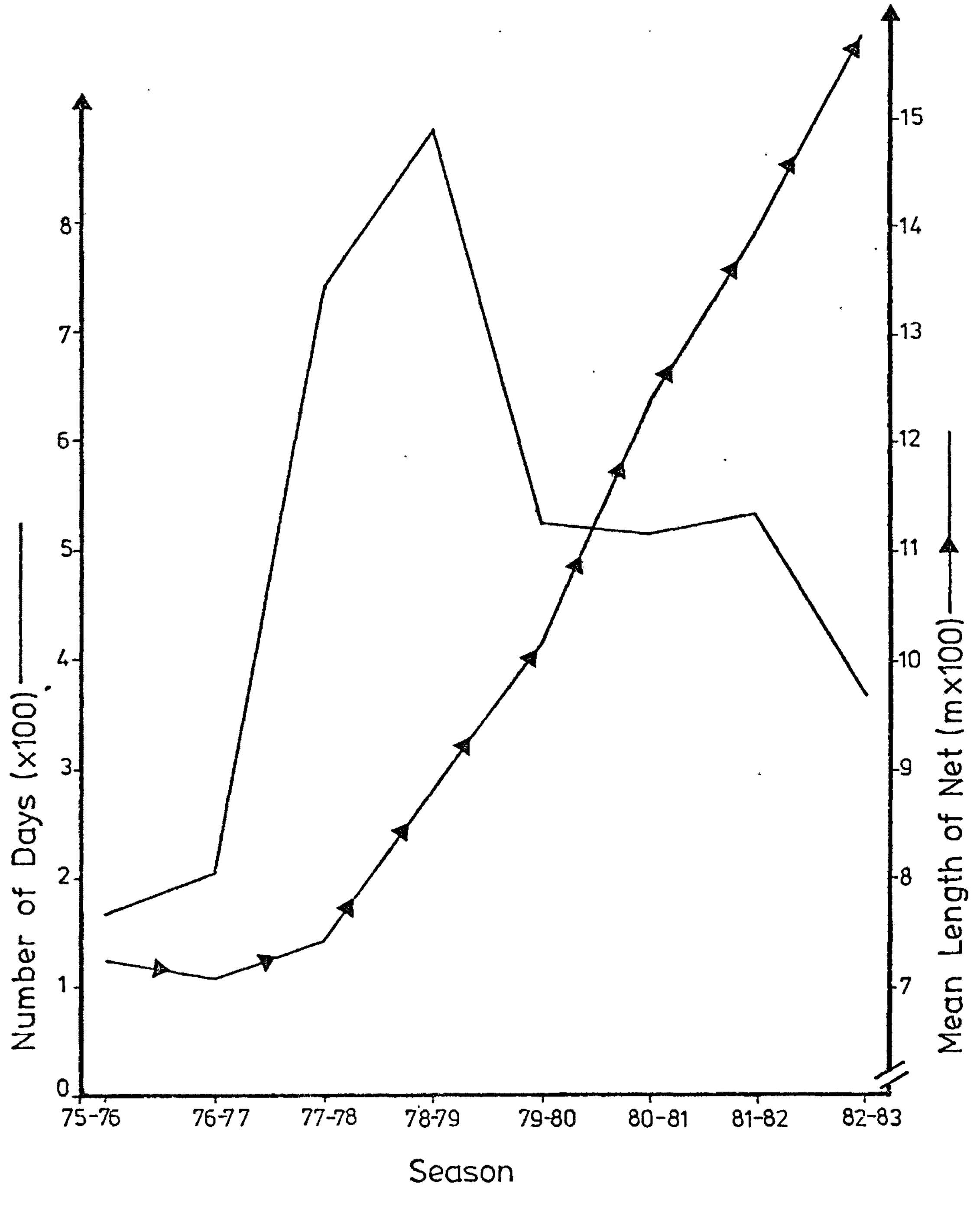

Figure 3.4 Total number of fishing days and mean length of net per vessel for set net vessels fishing in Pegasus Bay, 1975-1976 to 1982-1983. Values shown are only for the October-January period each season and they only include set net vessels fishing more than 350 metres of net. (Source: MAF unpubl. data).

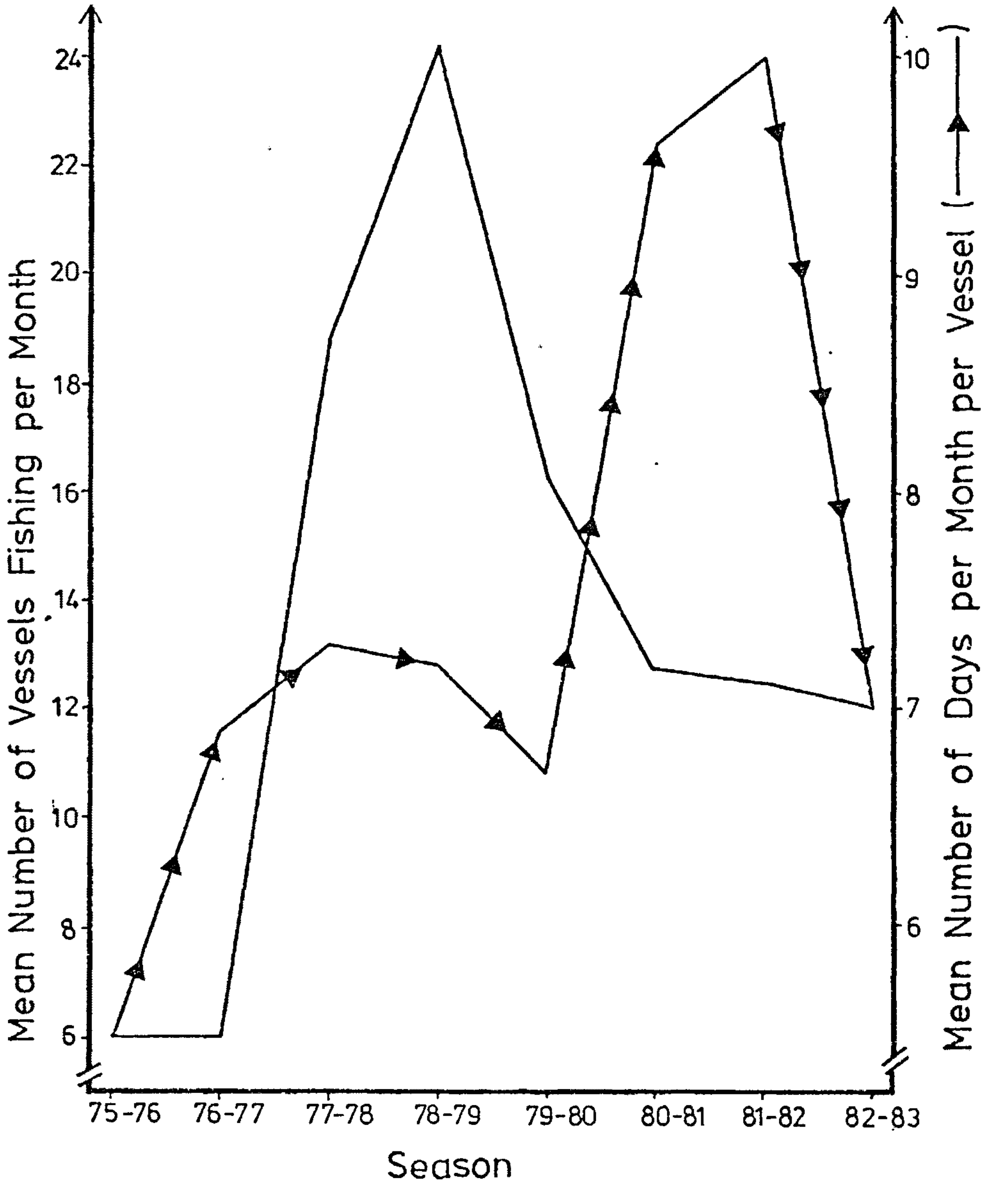

Figure 3.5 Mean number of set net vessels and mean number of fishing days per set net vessel for vessels fishing in Pegasus Bay, 1975-1976 to 1982-1983. Values shown are only for the October-January period and they only include set net vessels fishing more than 350 metres of net. (Source: MAF, unpubl. data).

days leapt nearly fourfold, and although there was no significant increase in the mean length of net fished (see Figure 3.4), effort still rose 270% above the previous season's level. This increased effort generated a 910% increase in the catch, taking it from the 1976-77 level of 19 t to 198 t for the 1977-78 season. Since the catch rose by considerably more than the effort, CPUE again rose rapidly to reach what was to be its peak of approximately 34 kg/100 m day.

The 1978-79 season was a turning point for the fishery. Although there was another large increase in effort (probably as a result of the previous season's success), the catch dropped slightly. The mean catch rate fell sharply therefore, as has been the general pattern ever since. This time the added effort was produced through increases in the total number of fishing days and the mean length of net (see Figure 3.4). The increase in the total number of fishing days arose through an increase in the mean number of vessels fishing per month. The mean number of days fished in each month per vessel fell slightly (see Figure 3.5).

In the 1979-80 season there was a substantial reduction in effort, taking effort back to the 1977-78 level. This was one reason for the huge (44%) drop in landings. The catch dropped by more than the effort, however, resulting in a further decline in CPUE.

Total effort increased again in the 1980-81 season. The greater effort was effected through an increase in the mean length of net being fished. The total number of fishing days was virtually the same as it had been in the previous season, despite the fact that the mean number of vessels fishing each month fell substantially for the second year in succession. As a result of the increase in effort, the catch staged a brief recovery. CPUE declined slightly, however.

Fishing effort increased to an all-time peak in the 1981-82 season. As with the previous season, the increase was augmented through the now regular increase in mean net length. The total number of fishing days remained virtually unchanged. Even with this extra effort, the catch fell by 22%. Consequently, CPUE declined abruptly yet again.

The 1982-83 season was notable for its low landings and significant reduction in effort. Although the mean length of net increased by a further 180 m (13%), effort decreased overall by 22%.

This resulted from a large decrease in the number of days fished. The catch also slumped to its lowest level in six years, partly because of the reduction in effort and partly because of another decrement in catch rate.

One of the most striking points to emerge from Figures 3.2 and 3.3 is that the catch and catch rate have never shown any prolonged stability. They both rose rapidly between 1975-76 and 1977-78 during the fishery's development phase, and simultaneously peaked in 1977-78. Since then, however, the catch rate has declined at a steady and rapid rate, as has the catch in all but one season. Both catch and CPUE have diminished at an average rate of approximately 14% per annum. It should be noted that the real decline in catch rate is probably more than this, as the catchability coefficient is probably not constant for the period examined (see discussion of assumption (iii) in section 3.3.1).

3.4.2 Interpretation of Trends

Fishery scientists are generally agreed that a simultaneous drop in both catch and catch rate signifies a reduced abundance of fish (Russell, 1942; Beverton and Holt, 1957). Thus, the classical interpretation of the observed decline would be that the average abundance of rig in Pegasus Bay is decreasing.

There are at least three other possible explanations for the decline in catch rate, which are not necessarily consistent with a decrease in the average abundance of fish, however. These are: first, that an increasing proportion of the fish are now only present in the bay before October or after January; second, that other fishing methods are collectively catching an increasing proportion of the available fish, leaving less for the set net fishermen; or third, that the fish are becoming more adept at avoiding capture.

If an increasing proportion of the fish were now only present in the months before October and after January, then we would expect to see the mean catch rate increasing in one or more of these months. We would also expect to see much more effort being applied in these months and therefore greater catches.

None of these trends is apparent in the data which are available.

The mean catch rate does not show a general increase for any of the months outside of the October - January period and overall, the mean catch rate for these months has declined since 1977-78. Fishing effort has shown a very small increase, but the catch has not. It too has declined since 1977-78. Thus it seems unlikely that the rig are now simply migrating into the bay at a different time.

The second explanation is equally dubious, as the amount of rig landed by other fishing methods (principally trawling) has not increased in parallel with the falling catch rate (see Figure 2.4). Landings for these methods have, in fact, been less since 1977 than they were in the 1974-77 period.

The third possibility is an interesting one as fish are indeed capable of learning to avoid capture. However, catch rates have sometimes fallen more than 30% in the space of one year and it seems difficult to believe that enough fish could learn fast enough to induce such a decline.

Since none of these alternative (non-classical) hypotheses provides a satisfactory explanation for the decline in catch rate, the classical interpretation appears to be the most likely explanation. A reduced abundance of rig in Pegasus Bay does not necessarily imply a reduced abundance of fish in the population, however. It could simply be that the fish are now migrating onto the continental shelf in other areas.

Although rig migrate along the coast once they have reached the shelf, there is evidence that many return to the same inshore grounds each summer (Mace, 1981; Francis, 1983a). If this is the case, then the decline in abundance could not result from changing migratory behaviour.

The results of catch-effort analyses for the three other major South Island rig fisheries (Tasman Bay - Golden Bay, Kaikoura and Timaru) also make it unlikely that the declining catch rate is attributable to changing migratory behaviour. All three of these fisheries have experienced declining catch rates. Thus, unless the fish which normally migrate onto the shelf in the Pegasus Bay area are now migrating onto the shelf south of the Canterbury Bight, the decline must be the result of a diminishing rig population. This conclusion is supported by Figure 3.6. The graph shows that catch rates in all four fisheries have declined at approximately the same rate in recent years.

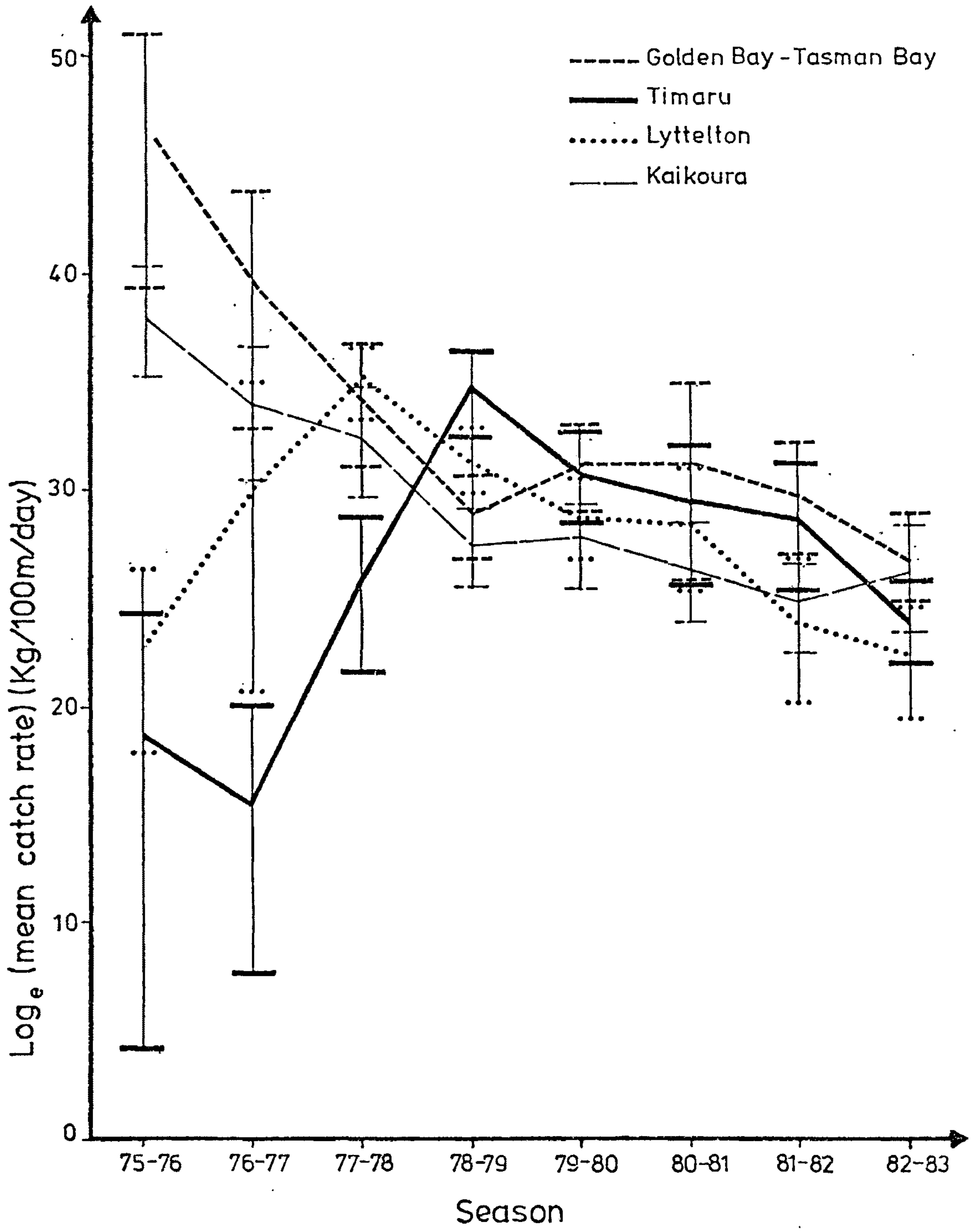

Figure 3.6 Log$_e$ (mean catch rate) for east coast South Island rig fisheries, 1975-1976 to 1082-1983. The mean catch rate is only calculated for set net vessels fishing more than 350 metres of net and for the peak four month catch rate period at each port. (Source: MAF, unpubl. data).

While there is no evidence to suggest that migratory behaviour has changed, there is some which suggests that the population is diminishing. It is concluded, therefore, that the decreasing abundance of fish in Pegasus Bay is the result of an overall decline in the abundance of rig in the east coast South Island population.

There are at least three possible explanations for the decline of the rig population. First, it could be part of a natural population fluctuation; second, it could be a consequence of excessive exploitation; or third, it could have resulted from some combination of these two phenomena.

Natural population fluctuations occur when a species experiences some change in its physical or biological environment. The most important way that physical environmental changes generate population fluctuations is by affecting juvenile mortality. Since rig offspring are large and well developed when they are born, they are probably fairly resilient to physical environmental changes. Unless the changes are severe, therefore, they are not likely to generate large population fluctuations directly.

Biological changes are also unlikely to induce large fluctuations in the rig population, as the species has few known predators and it does not constitute a large part of the diet of these predators. Furthermore, there is no reason to believe that the species' food supply has become any more scarce in recent years. With a reduction in the abundance of this and many other commercial species, it is quite possible that the dietary organisms are, in fact, more abundant now than they were several years ago.

Thus, from what is known about the biology of this and other closely related species, we would not expect to see a decline of the observed magnitude occurring naturally in such a short space of time. The only remaining explanation for the decline is that excessive exploitation is at least partly, if not wholly, responsible.

This explanation is substantiated by recent data obtained from the MAF rig research programme. Tagging work done in the 1982-83 season has shown that the east coast South Island rig stock is under very heavy fishing pressure. In the Kaikoura - Pegasus Bay region, 15.5% of all tagged fish were recaptured within the same season. This indicates that approximately 15.5% of the post-recruitment fish in this region were caught during the 1982-83 season. In several other regions on the east coast of the South Island, tag return rates were higher still. The true exploitation rate would be greater than these figures indicate, as some tags are not reported, some fish may lose their tags, and some fish may die as a result of the tagging procedure. Furthermore, the tagging year is not yet complete (Francis, 1983a). Thus, the estimated mortality rates are minimum possible values.

Even these minimum estimates indicate that the stock is very heavily exploited, however, as rig is a low productivity species (Francis, 1983b). Crossland (1982 *in* Francis, 1983b) has shown that many other New Zealand species which have similar ages at sexual maturity to that estimated for rig and which are presumed to have similar post-maturity growth rates and natural mortality rates (e.g., snapper and tarakihi), may be overfished at exploitation rates as low as 10%. Since rig is much less fecund (and therefore less productive) than these species, sustainable exploitation rates are probably in the order of 5% (M. Francis, pers. comm.).

Rig, being elasmobranchs, are probably not inherently resilient to overfishing. Thus the rapid decline in abundance and high exploitation rate are cause for concern in themselves. There is one aspect of exploitation which makes the situation even more serious however; that is, the very high rate of exploitation of females in the stock.

The MAF tagging experiments have shown that the minimum current exploitation rate of east coast females which are longer than 100 cm (the approximate length at which female rig mature) is 28% (M. Francis, pers. comm.). Female exploitation rates have probably also been high at least since the 1977-78 season, as inshore migration and set net effort deployment patterns have probably been similar since this time (see Figures 4.3 and 3.1 respectively). This high rate of exploitation will have reduced the number of mature females greatly. It has probably also reduced the average age and size of the females. Since female fecundity increases with the size of females (see Figure 4.6), the mean number of young per female has probably also declined. Thus, it is probable that these two factors have affected recruitment seriously as recruitment is probably directly related to the size of the rig stock (see section 1.2.1).

Both of these factors indicate that the present situation is more serious than the mortality estimates would lead us to believe. They indicate that future recruitment (and therefore the future health of the population) is probably also being severely affected. If the current pattern of exploitation continues, therefore, it is almost certain that the abundance of rig in the population will continue to decline at a rapid rate. Even if remedial measures were implemented immediately, population recovery would be slow.

The fundamental conclusion of this analysis is, therefore, that the abundance of rig is declining. This decline is attributed to overfishing. The cause of the decline is not of major importance, however, as regardless of the cause, fishing effort must be reduced if the population is to be harvested sustainably. If it is not, then there is good reason to believe that the future viability of this fishery is in jeopardy.

4.0 BIOLOGICAL ANALYSIS

4.1 INTRODUCTION

The ability of a fish stock to sustain a given level of production is determined by its size, its biological character, and its relationship to its physical and biological environments. Successful management of any stock depends, therefore, upon an adequate knowledge of the biological system.

Much of the biological research done by fishery scientists, is concerned with assessing the size and condition of fish stocks. This may be done in a variety of ways, but trawl, egg or acoustic surveys, tagging experiments, and commercial catch and effort data analysis are all frequently used. Each of these techniques provides information on the absolute or relative size of a stock, and so if one or more is conducted regularly, it should be possible to detect changes in stock abundance. Tagging experiments also provide very valuable information on exploitation rates. Catch and effort data are particularly useful for the reasons noted in section 3.1.

Since the condition of a stock is determined by its structure as well as its size, population structure monitoring is also integral to stock assessment. This may be done during research surveys or, alternatively, through commercial catch sampling programmes. Important parameters to monitor are the size, age and maturity of fish in the catch.

The other major area of investigation undertaken by fisheries scientists is research into the population dynamics of the exploited stock. This involves study of such things as growth rates, maturity, fecundity, natural mortality and recruitment. It should also provide at least an elementary understanding of the stock-recruitment relationship so that the impact of fishing may be evaluated or anticipated.

Environmental factors also exert a well-known influence on the dynamics of fish stocks. Thus, research should also seek to understand the relationship a species has with its physical and biological environments, as this will provide a valuable insight into the factors controlling natural mortality. Larkin (1978) suggests that the size of a year class is usually determined in its first year. If this is so, an understanding of the factors which control mortality in this first year is extremely useful, as it enables some prediction of the future state of a stock, and therefore, its yield.

All of these factors determine how productive a stock is and therefore the amount of fishing that the stock will be able to withstand. They also determine the way that the stock will react when it is fished at a given intensity. Thus, it is the interaction between these factors, the size of the stock and the prevailing fishing regime that determines the state of the stock. The two major areas of research noted are, therefore, complementary to each other. By combining the two sets of data, it should be possible to develop more sophisticated analytical techniques to aid in managing the stock.

The biological dimension of this study is obviously far too limited to allow an investigation of even a small fraction of these information requirements. It focuses, therefore, on the collection and analysis of some basic biological information as this is readily obtainable and fundamental to management of the fishery. It begins by examining the composition of commercial catches with respect to fish size, sex, and maturity, and then relates this to length at maturity. Fecundity and embryo characteristics have also been examined as fully as possible. It was not possible to age rig in this study, however, as there is no satisfactory technique for aging this species.

4.2 DATA COLLECTION AND METHODOLOGY

The biological data contained in this analysis were gathered during the course of a sampling programme conducted on board commercial fishing vessels throughout the 1982-83 season. Wherever possible, the entire catch was examined. With large catches, this sometimes became impracticable and in such cases it was necessary to take subsamples.

All fish examined at sea had their length, sex and sexual maturity recorded. Some were also weighed. The reproductive organs of mature fish were removed for laboratory examination. Length was measured to the nearest centimetre below total length as in Francis and Mace (1980). Weight was measured to the nearest 0.2 kg. Fish were categorised as mature, maturing or immature according to the classification in Appendix 2.

Laboratory examination of the male reproductive organs simply involved weighing the testes and their attached epigonal organ to obtain a combined weight. Weights were recorded to 0.1 g.

Female reproductive organs were firstly examined to determine the stage of the reproductive cycle at capture. Although this cycle is continuous, five discrete phases were recognised for convenience: virgin, recently ovulated eggs, yolked embryos, full-term embryos, and post-partum. The criteria used for classification are described in Appendix 3. If a fish was in the recently ovulated phase, the ovary was examined to determine whether ovulation was complete or not. Ovulation was judged complete when no large orange eggs remained in the ovary (Francis and Mace, 1980). Embryos were measured to the nearest millimetre below total length and once the yolk sac had been removed they were weighed to the nearest 0.1 g. Embryos larger than about 7 cm could also be sexed.

The uteri frequently contained eggs or embryos which would not produce viable offspring. Three types of reproductive failure were recognised; non-yolked uterine eggs, non-developing uterine eggs, and inviable embryos. Non-yolked eggs consisted of the egg case and albumen only, the yolk having been abnormally retained in the ovary. Non-developing eggs were those eggs which had been ovulated normally but which subsequently failed to develop into embryos. A uterine egg was recorded as non-developing if it had not shown any sign of producing an embryo by the time all the developing eggs contained embryos 5 cm long (Francis and Mace, 1980). Inviable embryos were embryos which were deformed; all but one of these embryos had large scars and abrasions over the head and sides of the body. These embryos also had much more fusiform bodies than healthy embryos and they frequently had muscle deformation. Furthermore, they were usually 3-5 cm shorter than the healthy embryos in a litter. Where present, these embryos were also counted.

Over the 1979-80 rig season, the MAF conducted a catch sampling programme on the Pegasus Bay rig fishery. This information had not been analysed but was made available to me by the Ministry. It serves as a valuable set of baseline data for comparison with the 1982-83 data.

Unfortunately, many of the data are unreliable as some fish longer than 100 cm were mismeasured. One data sheet contained numerous length measurements in excess of 150 cm, and since the largest rig recorded to date is 140 cm (M. Francis, pers. comm.), it is very unlikely that the measurements are correct. Because it was not always possible to detect erroneous measurements, none of the 1979-80 set net data were used for any analysis requiring adult length measurements. The trawl data are used to describe the length-frequency distributions of trawl catches, however, as they were the only commercial trawl data available. Since most fish were less than 100 cm long, the error rate is expected to be low.

4.3 CATCH COMPOSITION

4.3.1 Length

The size composition of a catch is influenced by the selective properties of the nets that are used to harvest the fish. Trawl nets have different selective properties from gill nets, and a trawl or gill net with one mesh size has different selective properties from another net with a different mesh size. It is necessary to account for these differences, therefore, when describing the length distributions of the catch. Table 4.1 shows the number of male and female fish sampled over each season and the mesh size and method by which these fish were caught (1979-80 set net data are not included. See section 4.2 above).

Table 4.1 Numbers of male and female fish sampled from trawl and set net catches.

Sample	Number of Fish		
	Males	Females	Total
Trawl			
(a) 15 mm mesh[a] (1982-83)	36	24	60
(b) 100 mm mesh[b] (1979-80)	62	20	82
(c) 125 mm mesh (1979-80)	20	15	35
Set Net			
(a) 178 mm mesh (1982-83)	272	277	549
(b) 165 mm mesh (1982-83)	101	44	145

a This sample was taken by the MAF research trawler, 'Kaharoa'.

b One female was also taken by a 100 mm trawl net in 1982-83. This is not included on the table.

Since rig school by size and sex, it is necessary to sample commercial catches on a number of different days and in a number of different locations, to describe adequately the commercial catch of any particular mesh size and method. For some of the groups shown in Table 4.1, this is not the case. Although the 165 mm mesh sample size is reasonable, more than 80% of the fish were sampled on one day, and so the sample is unlikely to be representative of the seasonal catch. Thus, the only set net length-frequency data used in the discussion of catch composition are the 178 mm mesh data. Sample sizes for both males and females are considered adequate and the samples were taken over a large number of days. The 165 mm mesh set net length-frequency distribution is shown in Appendix 1.

Although the trawl samples are small, these samples are analysed, as it is important to examine the differences between trawl and set net catch compositions. The 1979-80 samples were taken from a small number of trawl 'shots' (four for the 100 mm mesh sample and three for the 125 mm mesh sample), and while the 15 mm mesh sample was taken from a reasonable number of shots (10), it was taken during a period of only one week. It is necessary, therefore, to interpret the results cautiously. It should be noted that the 15 mm mesh sample is not a commercial catch; the sample was taken while on board the research vessel, 'Kaharoa'.

The length-frequency distributions of the trawl and 178 mm mesh set net samples are shown in Figures 4.1 and 4.2. Table 4.2 describes each of these distributions.

4.3.2 Sex

The relative proportion of males and females in commercial catches, varies with both the mesh size and time of year. The sex-composition of most samples cannot be examined adequately, however, either because there are too few fish in the sample or because the sample was not taken over a sufficiently long time span. The 178 mm mesh set net samples are the only samples suitable for analysis.

Table 4.3 shows the percentage of males and females in 178 mm mesh set net catches throughout the two sampling periods. The original sampling days are grouped into two-week intervals to obtain larger sample sizes. These data are shown graphically in Figure 4.3.

Table 4.2 Description of trawl and set net length-frequency distributions.

Sample	Length (cm)									
	Males in each size class (%)			Males		Females in each size class (%)			Females	
	<80	>100	>110	Mean	S.D.	<80	>100	>110	Mean	S.D.
Trawl[a]										
(a) 1979-80										
(i) 100 mm mesh	35.5	25.8	3.2	82.8	23.4	75.0	10.0	5.0	63.0	21.4
(ii) 125 mm mesh	80.0	0.0	0.0	68.8	16.0	73.3	6.7	0.0	64.4	20.7
(b) 1982-83										
(i) 15 mm mesh	78.4	0.0	0.0	66.3	13.7	87.0	4.3	0.0	66.0	13.0
Set Net										
(a) 1982-83										
(i) 178 mm mesh	4.8	32.0	2.9	96.1	8.9	4.7	47.3	9.0	98.4	12.0

[a] Source: MAF, unpubl. data.

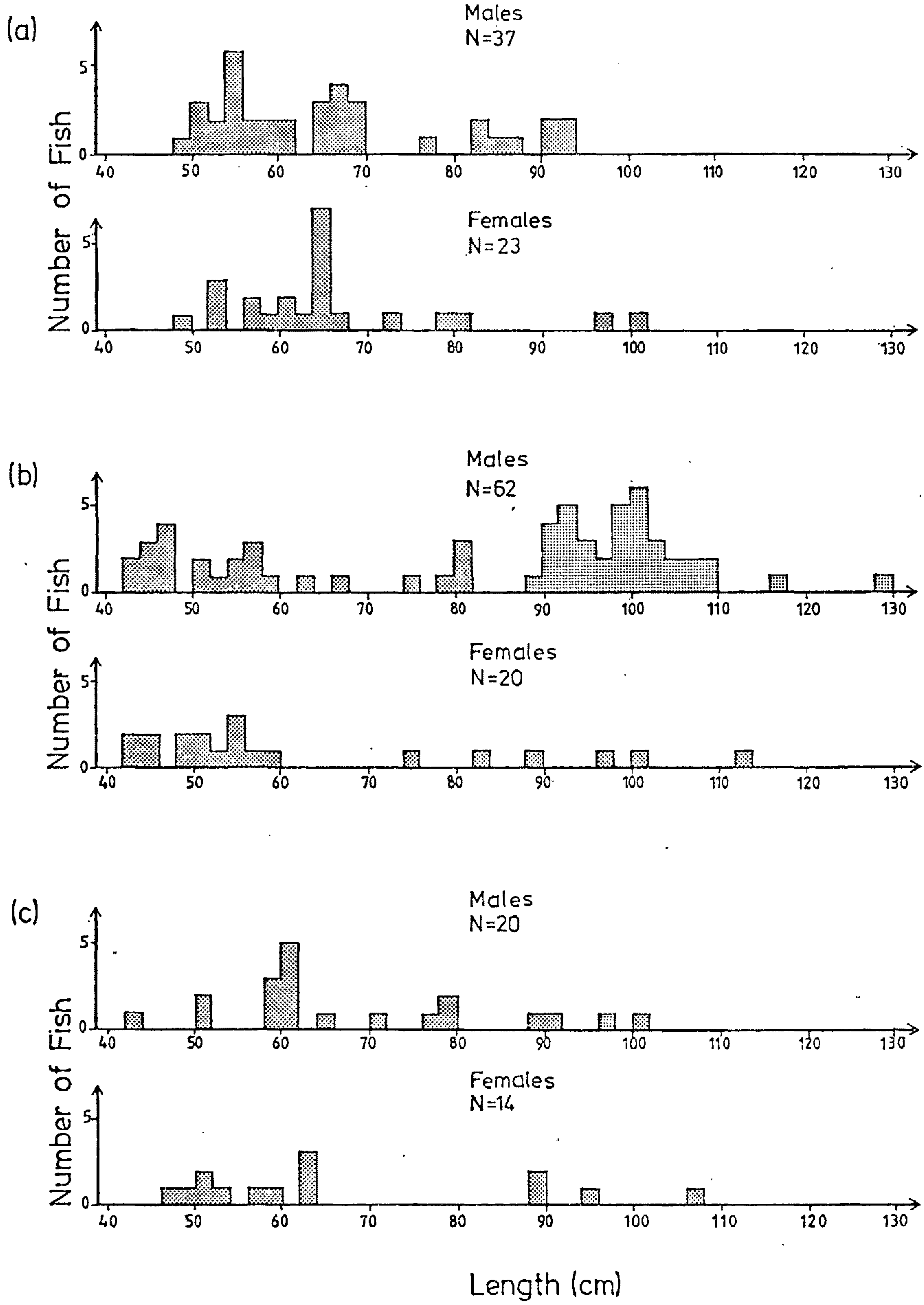

Figure 4.1 Length-frequency distributions (2 cm size class intervals) of male and female rig caught in trawl nets in Pegasus Bay, November 1979 - February 1980 and March 1983: (a) 15 mm mesh, 1983; (b) 100 mm mesh, 1979-1980, (c) 125 mm mesh, 1979-1980. (Source: MAF, unpubl. data).

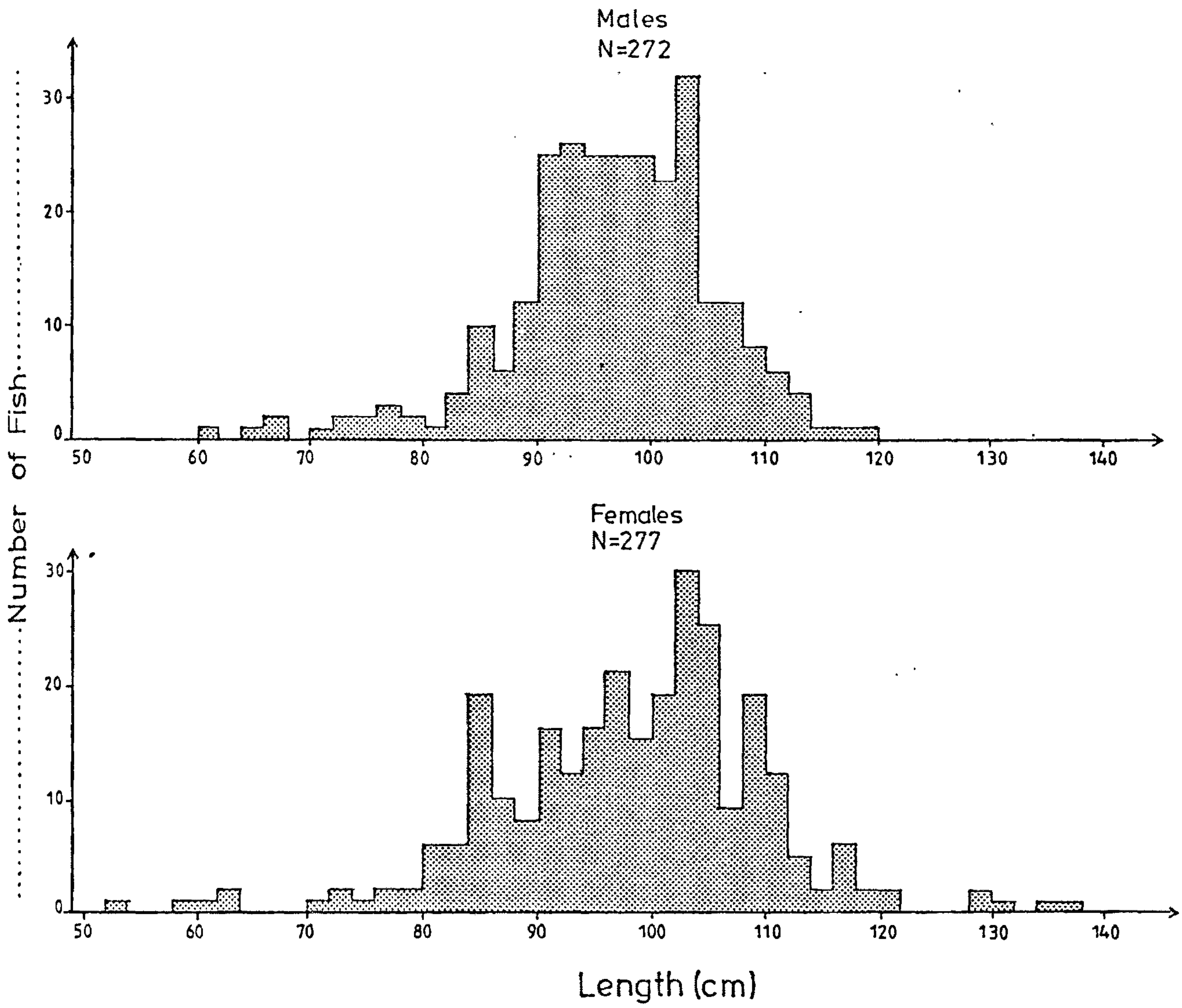

Figure 4.2 Length-frequency distributions (2 cm size class intervals) of male and female rig caught in 178 mm mesh set nets in Pegasus Bay, November 1982 - April 1983.

Table 4.3 Sex composition of 178 mm mesh set net catches throughout 1979-80 and 1982-83 seasons.

Time	Number of Fish		Sex (%) Male		Sex (%) Female	
	1979-80[a]	1982-83	1979-80[a]	1982-83	1979-80[a]	1982-83
Nov 1-14		40		73		27
15-30	204	64	93	67	7	33
Dec 1-14	262	132	93	66	7	34
15-31	89	55	89	85	11	15
Jan 1-14	56		43		57	
15-31	24	160	13	33	87	67
Feb 1-14	25		36		64	
15-28	38	63	3	10	97	90
Apr 1-14		35		13		87

[a] Source: MAF, unpubl. data.

4.3.3 Maturity

The relative proportions of mature and immature fish that are caught by each mesh size and method are important descriptors of catch composition. Once again it is important to compare the maturity composition of trawl and set net catches, and so the trawl data are analysed despite their shortcomings. The 178 mm mesh samples are the only set net data examined.

Rig examined during the 1979-80 season were only classified as mature or immature, while those examined during the 1982-83 season were classified as mature, maturing or immature. As the same criteria were used to judge full maturity in the two seasons, the percentage of fully mature fish taken in each season may still be compared for any one mesh size. These data are shown in Table 4.4.

If the maturity composition of catches varies throughout the season, the overall estimates of the relative proportions of mature, maturing and immature fish will be influenced by when the samples are taken. Thus it is necessary to determine whether the maturity composition of the

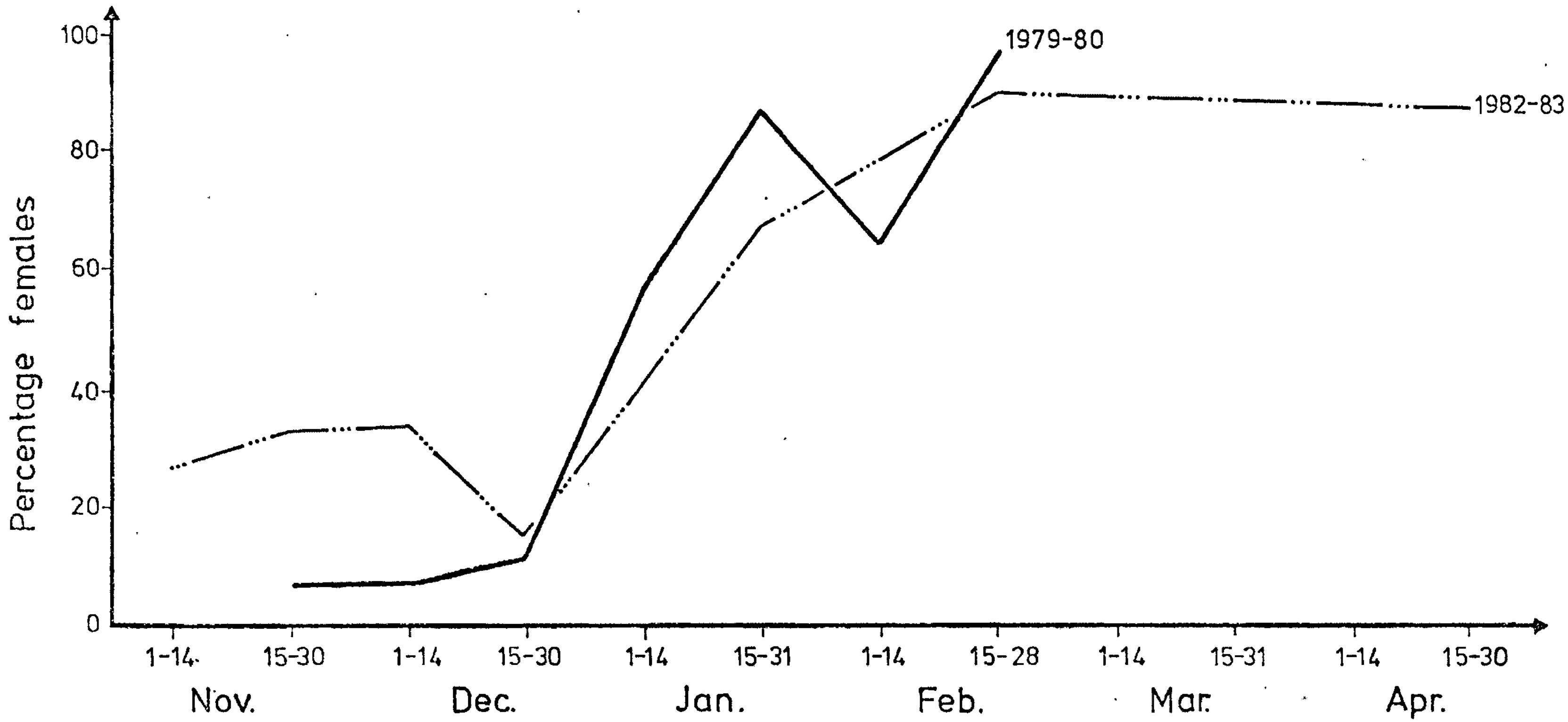

Figure 4.3 Percentage of females in 178 mm mesh set net rig catches from Pegasus Bay, November 1979 - February 1980 and November 1982 - April 1983. (Source of 1979-1980 data: MAF, unpubl. data).

catch does vary with time. Table 4.5 shows the percentage of fully mature males and females sampled in each time interval over the 1979-80 and 1982-83 seasons. The data are shown graphically in Figure 4.4.

Table 4.4 Maturity composition of trawl and set net samples.

Sample	Percentage of each Maturity					
	Males			Females		
	Immature[a]	Maturing	Mature	Immature[a]	Maturing	Mature
Trawl[b]						
(a) 1979-80						
(i) 100 mm mesh	52.4		47.6	95.0		5.0
(ii) 125 mm mesh	80.0		20.0	100.0		0.0
(b) 1982-83						
(i) 15 mm mesh	78.4	10.8	10.8	c	c	c
Set Net						
(a) 1979-80[b]						
(i) 178 mm mesh	3.9		96.1	45.8		54.2
(b) 1982-83						
(i) 178 mm mesh	5.9	11.4	78.7	50.7	21.3	27.9

[a] Contains maturing as well as mature fish for 1979-80 samples.

[b] Source: MAF, unpubl. data.

[c] Percentages not shown for these fish as the larger fish were tagged and returned to the water. This made it impossible to assess their maturity and would have biased the sample.

Table 4.5 Maturity composition of 178 mm mesh set net catches throughout 1979-80 and 1982-83 seasons.

Time	Number of Fish				Percentage Mature			
	Males		Females		Males		Females	
	1979-80[a]	1982-83	1979-80[a]	1982-83	1979-80[a]	1982-83	1979-80[a]	1982-83
Nov 1-14		29		11		93		64
15-30	82	43	10	21	98	86	50	43
Dec 1-14	85	87	29	45	99	79	31	24
15-31	34	47	10	8	100	92	50	38
Jan 1-14	17		16		88		38	
15-31	3	52	15	108	67	67	60	29
Feb 1-14	9		7		67		43	
15-28	1	6	30	57	100	100	90	23
Apr 1-14		4		31		100		16

[a] Source: MAF, unpubl. data.

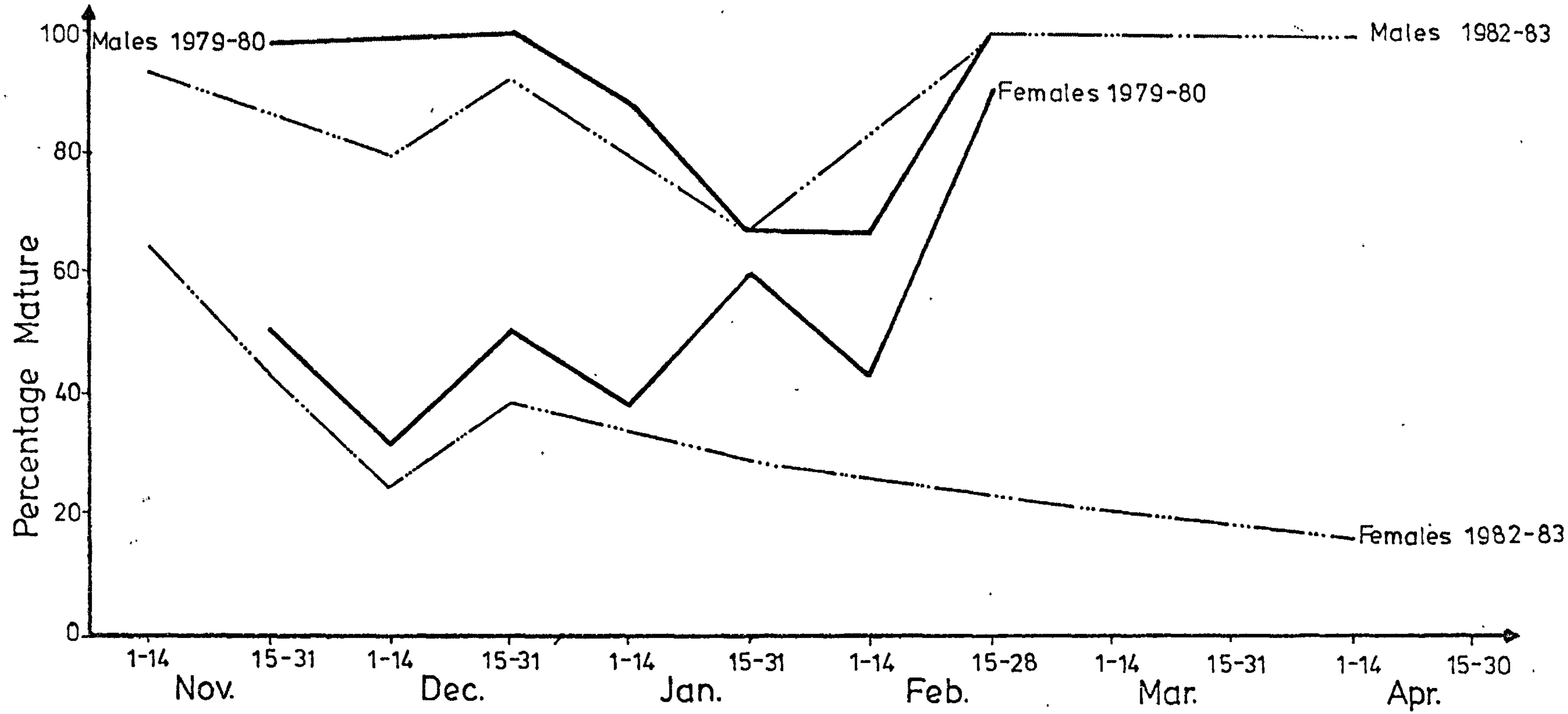

Figure 4.4 Percentage of mature male and female rig in 178 mm mesh set net catches from Pegasus Bay, November 1979 - February 1980 and November 1982 - April 1983. (Source of 1979-1980 data: MAF, unpubl. data).

4.4 SPECIES' CHARACTERISTICS

4.4.1 Growth

A. Adult

Since no satisfactory aging technique has yet been developed for this species, it is impossible to investigate the growth characteristics of adult rig very fully. The only feature which can be investigated is the length-weight relationship for each sex.

The length and weight data show that rig increases exponentially with length. Thus the length-weight relationship is of the form,

$$W = a\,L^{b} \qquad (4.1)$$

where,

W = green weight (kg)
L = total length (cm)
a = Y-intercept
b = regression coefficient.

If the length and weight variables are transformed using natural logarithms, then the relationship between the two transformed variables becomes,

$$\ln W = \ln a + b \ln L \; . \qquad (4.2)$$

Since this relationship is linear, the values of a and b may be determined by linear regression of $\ln W$ on $\ln L$.

When the untransformed length and weight data were examined, it was found that both the male and female data sets are heteroscedastic[1]. If this effect is not removed before the regression line is fitted, the estimates of a and b will be biased, as one of the assumptions of linear regression is that the variance of Y is independent of X. Ordinary natural logarithm transformations do remove much of this bias, but it is possible to improve the homogeneity of the variance considerably by restating equation (2) as,

---

[1] The variability in weight increases with length.

$$\frac{\ln W}{\ln L} = \frac{\ln a}{\ln L} + b \tag{4.3}$$

and then calculating the regression of $\ln W/\ln L$ on $1/\ln L$ (Chatterjee and Price, 1977). Before the regression line is fitted, however, it is necessary to correct all recorded lengths by a factor of 0.5 cm. This is because fish were measured to the nearest centimetre below total length and are, therefore, on average 0.5 cm larger than the recorded lengths would indicate.

A least squares regression of $\ln W/\ln L$ on $1/\ln L$ for male rig gives,

$$\frac{\ln W}{\ln L} = \frac{-11.827}{\ln L} + 2.859 \tag{4.4}$$

(n = 185; $s.e.$[1]$_{\ln a}$ = 0.312; $s.e._b$ = 0.068; r = 0.942).

The regression for female rig gives,

$$\frac{\ln W}{\ln L} \quad \frac{-13.198}{\ln L} + 3.171 \tag{4.5}$$

(n = 153; $s.e._{\ln a}$ = 0.323; $s.e._b$ = 0.071; r = 0.958).

Using antilogarithms in these two equations, the relationship for male rig becomes,

$$W = 7.305 \times 10^{-6} L^{2.859} \tag{4.6}$$

with 95% confidence intervals for a and b of,

$$3.939 \times 10^{-6} < a < 1.355 \times 10^{-5}$$

and

$$2.179 < b < 2.999 \; .$$

The relationship for female rig becomes,

$$W = 1.855 \times 10^{-6} L^{3.171} \tag{4.7}$$

---

[1] Standard error

with 95% confidence intervals of,

$$9.788 \times 10^{-7} < a < 3.515 \times 10^{-6}$$

and

$$3.031 < b < 3.311 \ .$$

The regression coefficients of equations 4.6 and 4.7 are significantly different at the 5% significance level (z = 3.163; $0.001 < P < 0.002$), as are the Y-intercepts (z = 6.189; $P << 0.0002$). Thus the relationship between length and weight is different in male and female rig.

The estimate of a and b obtained for each sex, cannot be tested against the estimates obtained by Francis (1979) for Kaikoura rig, as no measures of variability are included with Francis' estimates. However, Francis found no significant difference between the regression coefficients for male and female rig (t = 1.45; d.f. = 190; $0.1 < P < 0.2$). While the Y-intercepts did differ significantly for Kaikoura rig (t = 143.2; d.f. = 190; $P << 0.001$), it was found that the Y-intercept for female rig was higher than the Y-intercept for male rig. This is anomalous with the results obtained in this study.

Although the correlation coefficients are large for each of the regression equations, the length and particularly the weight were sometimes subject to considerable measurement error. Furthermore, there is a lot of natural variability between fish with respect to both of these variables. Under these circumstances, the predictive regressions just described are biased and they should not be used to predict the weight of a fish if the length is known. Ricker (1973) notes that the geometric mean regression is the best regression to describe a relationship where these conditions prevail.

The geometric mean regression is of the form,

$$Y = u + vX \tag{4.8}$$

where,

$$v = b/r \tag{4.9}$$

with,

b = slope of predictive regression line, and

r = correlation coefficient of predictive regression line.

Fitting the data from the predictive regression equations, it is found that the geometric mean regression equation for male rig is,

$$W = 3.355 \times 10^{-6} L^{3.035} \tag{4.10}$$

with 95% confidence intervals for u and v of,

$$2.917 \times 10^{-6} < u < 3.859 \times 10^{-6}$$

and

$$2.949 < v < 3.121 .$$

The geometric mean regression for female rig is,

$$W = 1.060 \times 10^{-6} L^{3.310} \tag{4.11}$$

with 95% confidence intervals for u and v of,

$$9.217 \times 10^{-7} < u < 1.220 \times 10^{-6}$$

and

$$3.226 < v < 3.394 .$$

These equations may be used to predict the weight of a rig if the length is known. They cannot be tested for significance, however (Ricker, 1973), and hence predictive regressions are also performed.

B. Embryo

Since very few female fish were found with embryos in the size range 5 - 25 cm, it is not possible to describe the length-weight relationship for embryonic rig.

Rig appear to have a gestation period of between 10 and 11 months (Graham, 1956; Francis, 1979; Francis and Mace, 1980). Thus, although embryonic rig cannot be aged, it is possible to describe their growth through time by examining the relationship between embryo length and time of the year. Figure 4.5 shows the length-frequency distributions of embryonic rig for the November 1979 - February 1980 and November 1982 - April 1983 periods. The lengths shown are mean lengths for all viable embryos in each litter.

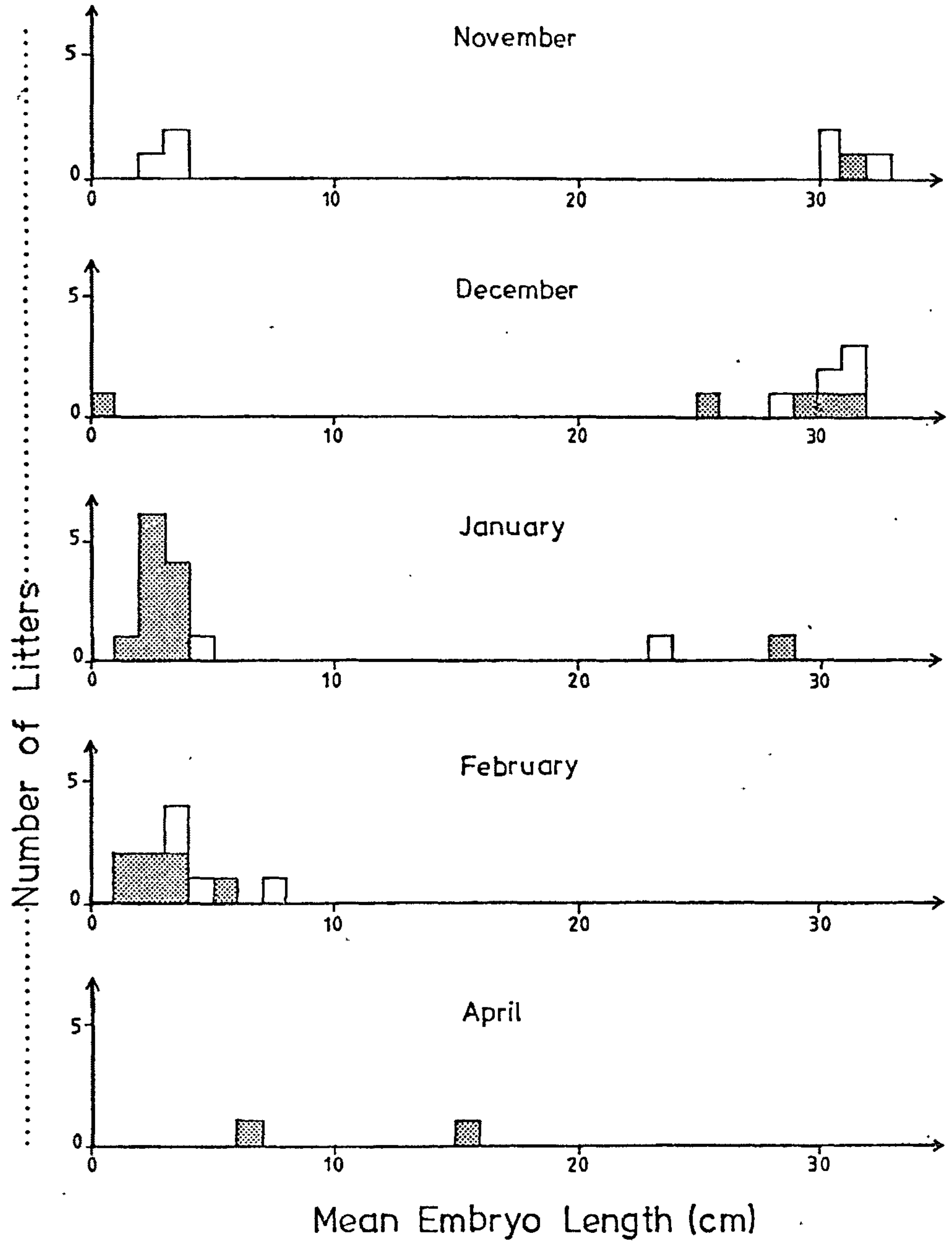

Figure 4.5 Frequency distributions (1 cm size class) of mean embryo length for rig in Pegasus Bay, November 1979 - February 1980 (unshaded) and November 1982 - April 1983 (shaded). (Source of 1979-1980 data: MAF, unpubl. data).

4.4.2 Reproduction

A. Male

(a) Length at maturity

Since gill nets may be selective with respect to maturity (Hamley, 1975), it is not possible to amalgamate all of the available set net data to estimate the length at which either male or female rig from the Pegasus Bay region become sexually mature. It is also not possible to combine the 1979-80 and 1982-83 set net data for any one mesh size, as the length of maturity may be density-dependent. The only data used to estimate the length at sexual maturity are, therefore, the 1982-83 178 mm mesh data. Table 4.6 shows the percentage of mature, maturing and immature male fish in this sample.

(b) Gonad index

In teleost fish, spermatozoa are usually discharged from the body when testis activity is greatest (Mizue, 1958 *in* Teshima, 1978). In two Japanese *Mustelus* species, *M. manazo* and *M. griseus*, however, discharge occurs when testis activity is lowest (Teshima, 1978). The different reproductive activity of these species is due to structural differences in the two male reproductive systems (Teshima, 1978).

Since discharge only occurs during mating, the timing of mating may be inferred from information on testis activity if the structure of the male reproductive system is known. Testis activity may be monitored by examining changes in gonad index, where

$$\text{Gonad index (\%)} = \frac{\text{weight of testes (g)}}{\text{weight of fish (g)}} \times 100 .$$

Table 4.7 shows the gonad index of males taken from Pegasus Bay during 1982-83 and from Kaikoura during 1978-79.

B. Female

(a) Length at maturity

Table 4.8 shows the percentage of mature, maturing and immature female fish in the 1982-83 178 mm mesh set net sample.

Table 4.6 Sexual maturity of male rig caught in 178 mm mesh set nets in Pegasus Bay, November 1982 - April 1983.

Length (cm)	Number of Fish	Percentage of each Maturity		
		Immature	Maturing	Mature
71	1	100		
73	2	100		
75	1	100		
76	2	100		
77	1		100	
78	1	100		
79	1		100	
81	1		100	
82	2		50	50
83	3	33	67	
84	1		100	
85	8		75	25
86	3	33	33	33
87	3	67	33	
88	9	11	33	56
89	3		67	33
90	9		11	89
91	16		19	81
92	11		18	82
93	15		13	87
94	16		25	75
95	9			100
96	13			100

Note: (a) 4 fish which were shorter than 70 cm are not shown; all were immature. 135 fish longer than 96 cm are also not shown. One 105 cm fish and one 112 cm fish were immature, but all others were mature.

(b) Table contains some rounding errors.

Table 4.7 Gonad index of male rig caught in Pegasus Bay, 1982-83 and at Kaikoura, 1977-78.

Month	Number of Fish		Gonad Index (%)			
			Pegasus Bay		Kaikoura[a]	
	Pegasus Bay	Kaikoura[a]	Mean	S.E.	Mean	S.E.
Sep		4			1.09	0.09
Oct		4			0.83	0.13
Nov	17	9	0.65	0.04	0.97	0.03
Dec	53	6	0.85	0.02	0.99	0.07
Jan	13	1	0.79	0.04	1.17	
Feb	2	20	0.81	0.13	0.98	0.04
Mar		6			1.09	0.06
Apr	2	1	0.94	0.06	1.25	

[a] Source: Francis, 1979

Table 4.8 Sexual maturity of female rig caught in 178 mm mesh set nets in Pegasus Bay, November 1982 - April 1983.

Length (cm)	Number of Fish	Percentage of each Maturity		
		Immature	Maturing	Mature
90	9	89	11	
91	7	100		
92	7	71	29	
93	5	100		
94	8	88	13	
95	8	88	13	
96	11	82	18	
97	10	80	10	10
98	9	44	33	22
99	6		50	50
100	5	20	60	20
101	14	50	36	14
102	10	30	30	40
103	19	16	63	21
104	11	9	45	45
105	14	14	57	29
106	8	38		63
107	1			100
108	8		63	38
109	11			100
110	9			100

Note: (a) 30 fish shorter than 90 cm, are not shown; one 86 cm fish and one 89 cm fish were maturing, but all others were immature. 12 fish longer than 110 cm are also not shown; one 111 cm fish and one 113 cm fish were immature, and one 112 cm fish was maturing, but all others were mature.

(b) Table contains some rounding errors.

(b) Reproductive cycle

To determine the overall timing of the female reproductive cycle, all relevant data obtained during the 1982-83 season are treated together. Ninety percent (n = 70) of this data came from 178 mm mesh set net catches, with the remaining 10% being collected from fish caught in 165 mm mesh nets.

Table 4.9 shows the percentage of fish in each reproductive phase for the November 1982 - April 1983 period. Three virgin fish are not shown. Three fish which contained only non-yolked eggs are also not shown, as it is not possible to determine when these eggs were released into the uteri. Thus the percentages shown in the table are percentages of the fish that were, or had been, pregnant and for which it was possible to determine the phase of the reproductive cycle. Table 4.10 shows the percentage of mature female rig in each reproductive phase for samples taken at Kaikoura and Nelson. The values are again percentages of the fish that were, or had been, pregnant; the two seasons' data for Kaikoura are amalgamated.

Table 4.9 Percentage of mature female rig in each reproductive phase (Pegasus Bay, 1982-83).

Month	Number of Fish	Reproductive Phase (%)[a]			
		Full-term embryos	Post-partum	Recently ovulated	Yolked embryos
Nov	8	12.5	25.0	62.5	0.0
Dec	21	19.0	28.6	42.9	9.5
Jan	21	9.5	4.8	28.6	57.1
Feb	12	0.0	25.0	25.0	50.0
Apr	4	0.0	50.0	0.0	50.0

[a] Percentage of mature female fish which were, or had been, pregnant and for which it was possible to determine the phase of the reproductive cycle.

While the data on the female reproductive cycle were being collected, it was noticed that only large female rig were ever pregnant with full-term embryos. Furthermore, it was noted that nearly all large female rig were pregnant with full-term embryos. This suggested that large female rig may give birth and mate later than small female rig. Table 4.11 shows the percentage of each size class of mature females that contained recently ovulated eggs or young embryos, the percentage that had recently given birth to a litter but had not yet ovulated a new set of eggs. The six fish not included in Table 4.10 are also excluded from Table 4.11.

Table 4.10 Percentage of mature female rig in each reproductive phase (Kaikoura, 1977-79 and Nelson, 1978-79)[a].

Month	Number of Fish	Reproductive Phase (%)[b]			
		Full-term embryos	Post partum	Recently ovulated	Yolked embryos
Kaikoura					
Sep	7	0.0	0.0	100.0	0.0
Oct	15	0.0	13.3	86.7	0.0
Nov	36	8.3	2.8	88.9	0.0
Dec	20	5.0	20.0	50.0	40.0
Jan	12	8.3	0.0	50.0	41.7
Feb	13	0.0	7.7	38.5	53.8
Mar	15	0.0	13.3	13.3	73.4
Apr	30	0.0	10.0	0.0	90.0
May	2	0.0	0.0	0.0	100.0
Nelson					
Oct	5	0.0	0.0	100.0	0.0
Nov	21	14.3	4.8	4.8	76.2
Dec	10	0.0	10.0	10.0	80.0
Jan	26	0.0	0.0	0.0	100.0
Feb	13	0.0	0.0	0.0	100.0
Mar	10	0.0	0.0	0.0	100.0
Apr	1	0.0	0.0	0.0	100.0

[a] Source: Modified from Francis and Mace (1980)

[b] Percentages of mature female fish which were, or had been, pregnant and for which it was possible to determine the phase of the reproductive cycle.

Table 4.11 Percentage of each size class of mature female rig in full-term, post-partum and recently ovulated or yolked embryo reproductive phases.

Size Class (cm)	Number of Fish	Reproductive Phase (%)[a]		
		Full-term embryos	Post-partum	Recently ovulated or yolked embryos
≦100	6	0.0	16.7	83.3
101 - 110	41	2.4	19.5	78.0
110 - 120	13	0.0	38.5	61.5
≧121	6	100.0	0.0	0.0

[a] Percentages of mature females which were, or had been, pregnant and for which it was possible to determine the phase of the reproductive cycle.

(c) Fecundity

Reproductive failure and fecundity are also examined using all of the set-net data collected during the 1982-83 season.

Since reproduction may fail at one of several stages in the female reproductive cycle, it is difficult to determine the relationship between the size of the female and the number of viable offspring. Embryos must be large enough to make the possibility of further members of the litter becoming inviable, small, and they must be less than full-term size, as if full-term embryos are present then there is a possibility that some young have been born already. The limits of this range are not known. Even a measure of the total number of mid-term embryos is difficult to obtain as very few female fish were found to contain embryos in this range. Similar difficulties have been encountered in other studies.

The only relationship which can be investigated, therefore, is that between the size of female rig and the total number of ovulated eggs (excluding non-yolked eggs). To investigate this relationship, it is necessary to exclude fish which have not finished ovulating and fish which contain full-term embryos; including these fish would lead to errors by underestimating the true relationship.

Although the appropriate sample is still of a reasonable size ($n = 33$), the data do pose problems. The first is that the data are highly variable. The second is that most of the observations occur over a very narrow length range. Only 24% of the observations are from fish longer than 110 cm and only 9% are from fish longer than 115 cm. Since the length-fecundity relationship is exponential, the observations from large fish are very important.

In view of these two factors, it is considered impracticable to fit a regression line to the data. The data are shown in Figure 4.6, however, along with the length-fecundity (number of uterine eggs or embryos) relationships which have been calculated for rig in the Nelson and Kaikoura regions.

Of the 53 fish that contained eggs or embryos during the sampling programme, 64.2% contained one or more non-yolked eggs. The largest number of non-yolked eggs in a female was seven (out of a total of eight

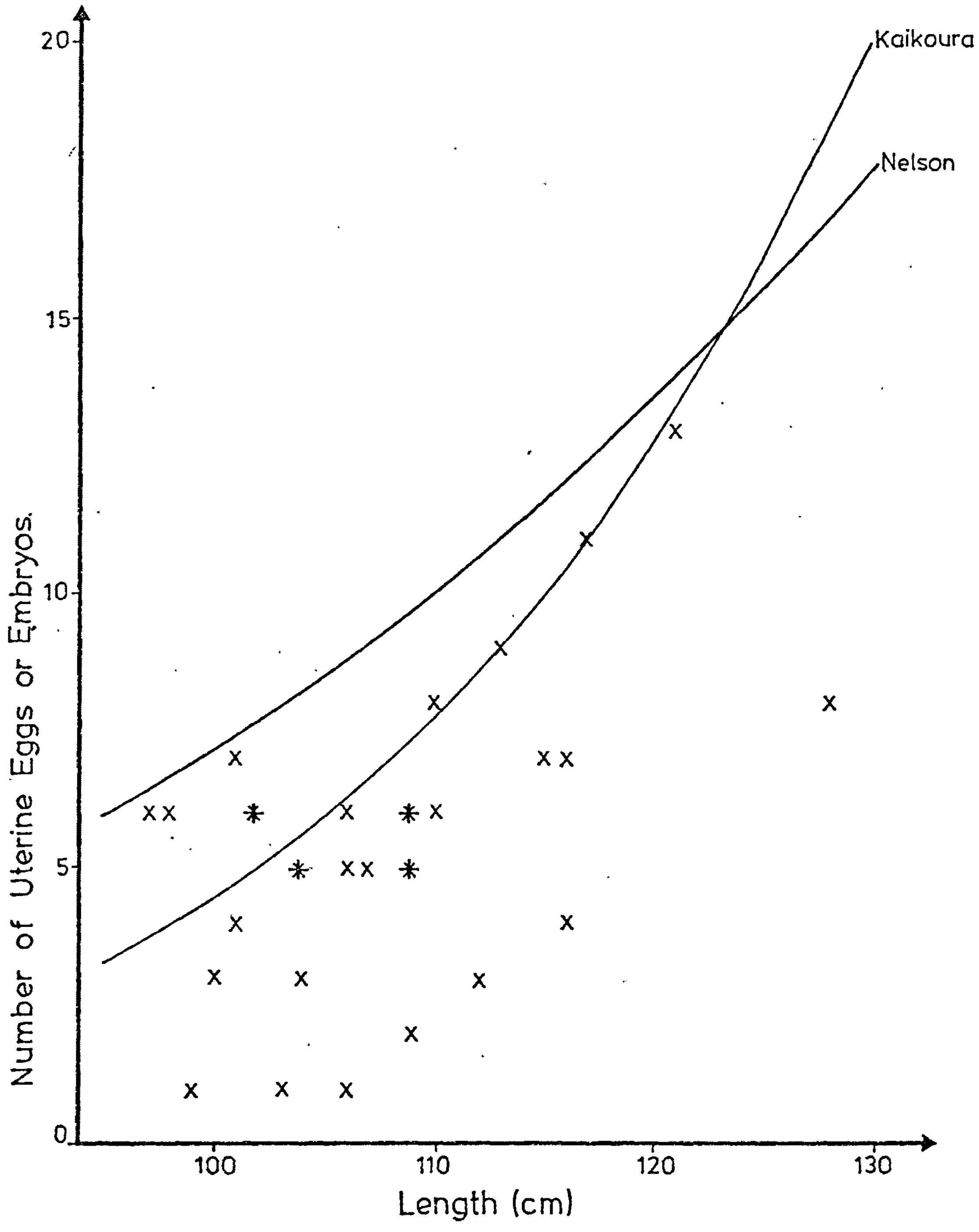

Figure 4.6 Length-fecundity relationship in rig from Pegasus Bay, November 1982 - April 1983. Asterisks denote more than one fish. (Source of Nelson and Kaikoura regression lines: Francis and Mace, 1980).

reproductive events[1]). Of the fish which had finished ovulating and which contained embryos smaller than full-term size ($n = 33$), 63.6% contained non-yolked eggs. The largest number of non-yolked eggs found in one of these fish was five (out of a total of six reproductive events) and the mean number was 1.03 ($s = 1.13$). Of a total of 199 reproductive events in these fish, 34 (17.1%) were non-yolked.

To test whether there is any significant difference between the number of non-yolked eggs and the size of fish, the regression of number of non-yolked eggs on fish length was calculated. A least squares regression showed that there was no significant relationship between the two variables ($t = -0.146$; d.f. = 31; $P \gg 0.5$). Since fecundity increases exponentially with length, this suggests that the proportion of total reproductive events which are non-yolked, decreases in larger fish. When the regression of percentage of reproductive events which were non-yolked on fish length was calculated, however, the relationship was also not significant ($t = 1.471$; d.f. = 31; $0.1 < P < 0.2$). It is concluded, therefore, that there are too few data to ascertain a relationship.

It is also difficult to determine whether the mean percentage of reproductive events that are non-yolked, is the same in those fish which have finished ovulating and are carrying less than full-term embryos, as it is in the fish which have not finished ovulating. If this could be determined, it would indicate whether non-yolked eggs are more or less prevalent among the last eggs which are ovulated. In the data set containing the fish which had not finished ovulating, however, 2 or 3 fish were found to contain very high numbers and proportions of non-yolked eggs. These fish appear to exert a large influence on the outcome of the test. If they are left in the data and the test is performed, then the difference between the two means is highly significant ($t = 8.513$; d.f. = 46; $P \ll 0.001$). If these data (and one outlier in the other data set) are removed, then the difference between the means is not significant at the 5% significance level ($t = 1.009$; d.f. = 46; $0.2 < P < 0.4$). Thus, no conclusions can be drawn. Observation suggests, however, that non-yolked eggs are not more prevalent towards the end of ovulation. The non-yolked eggs appeared to occur randomly throughout the uteri.

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[1] A reproductive event is defined as any uterine occurrence, i.e., a non-yolked egg, a non-developing egg, an inviable embryo or a viable embryo.

To obtain an accurate estimate of the frequency with which eggs fail to develop, it would be necessary to examine a large number of fish containing embryos longer than 5 cm but less than full-term size. Unfortunately, very few of the fish (only four of the 72 mature females examined) contained embryos in this size range. All four of these fish contained non-developing eggs, however. Of the 44 eggs or embryos present in these females, six (13.6%) had failed to develop. When the females containing full-term pups are included, it is found that eight (80%) of the females contained non-developing eggs.

It is also impossible to determine the rate or size at which embryos become inviable during development. The smallest inviable embryo observed in this study was 9 cm and the largest was 24 cm. Of the eight females containing embryos longer than 9 cm, four (50%) contained inviable embryos. One female (*T*) contained 16 inviable embryos (out of a total of 17 reproductive events), but all others contained less than five. The total number of inviable embryos (excluding female *T*) was eight, or 8.8% of the total number of embryos. The mean number of inviable embryos (excluding female *T*) was 1.1 ($n = 7$; $s = 1.68$) per fish. The proportions of inviable male and female embryos were not significantly different from the expected 1:1 ratio at the 5% significance level ($X^2 = 0.50$; d.f. = 1; $0.25 < P < 0.5$).

(d) Embryos

A total of 81 embryos were sexed in this study, 43 (53.1%) of which were females. The observed ratio of males and females did not differ significantly from the expected ratio of 1:1 at the 5% significance level ($X^2 = 0.31$; d.f. = 1; $0.25 < P < 0.5$). The mean lengths of male and female embryos and the mean weights of male and female embryos did not differ significantly at the 5% significance levels ($t = 1.309$; d.f. = 25; $0.2 < P < 0.4$ and $t = 1.905$; d.f. = 25; $0.05 < P < 0.1$). The largest embryo was 32 cm long.

4.5 DISCUSSION

4.5.1 Catch Composition

Since the trawl samples are small, it is necessary to be cautious when interpreting them. The length-frequency distributions suggest that there are some major differences between the composition of trawl and set net catches, however.

Trawl catches appear to contain many small immature fish. Very few of the males and females sampled from any of the trawl catches were longer than 100 cm, and fish longer than 110 cm were rare. For this reason, the majority of fish were immature, although the earlier maturation of males does result in a considerably larger proportion of mature males being caught. Since trawlers generally appear to catch small fish, the maturity composition of the catch is unlikely to change greatly over a season.

The small proportion of large fish in trawl catches suggests that larger fish are able to avoid capture. This would seem to be quite possible as rig have a well-developed lateral line system and they are powerful swimmers (Francis, 1979).

Although the sample sizes are small, the results are consistent with other data on trawl catches of rig. Large samples of rig taken from trawl catches in the Hauraki Gulf and on the west coast of the North Island, were also conspicuously lacking in large fish, even though large fish are thought to have been reasonably abundant at the time that these samples were taken (Francis, 1979; M. Francis, pers. comm.).

In contrast to trawl catches, set net catches were composed of much larger fish. Consequently, a much greater proportion of the fish taken in set nets was mature. There are some notable differences between the length composition of male and female samples.

Very few of the males sampled from set net catches were shorter than 80 cm and only 17% were shorter than 90 cm. Similarly, only a small proportion of the males were longer than 110 cm, with the maximum recorded size being 119 cm. This compares closely with the maximum sizes of males observed at Kaikoura (114 cm) and Nelson (115 cm) (Francis and Mace, 1980) Since nearly all of the fish were mature at 90 cm, the vast majority of male fish sampled was mature.

As with the male set net sample, very few of the female fish from set nets were less than 80 cm long. A larger proportion of female fish was greater than both 100 cm and 110 cm, however. Overall, the mean size of females was significantly larger than the mean size of males ($t = 2.03$; d.f. = 509; $0.01 < P < 0.25$). Furthermore, seven female fish (2.2% of the female sample) were longer than the largest male, with the longest female being 136 cm. This indicates that female rig grow to a larger size than males, as, if larger males had been present, they would be expected to be caught along with the large females. The longest female rig recorded in Pegasus Bay, was of a similar size to that recorded at Kaikoura and Nelson. The largest female fish observed at Kaikoura was 137 cm and the largest observed at Nelson was 129 cm (Francis and Mace, 1980).

Although a larger proportion of the female fish was longer than 100 cm, fewer caught in set nets in either 1979-80 or 1982-83 were mature because females mature at a larger size than males. Very few of the female rig were mature at 100 cm; overall, only about 30% of the female fish from 178 mm mesh set nets in 1982-83 were fully mature.

Figure 4.4 shows that there are also some notable differences in the way that the maturity composition of male and female samples changed throughout the season. It also shows some significant differences between the two seasons examined.

In the 1979-80 season, the percentage of males that were mature[1] remained approximately constant throughout November and December and then dropped off markedly in January. This same trend appears to have occurred in the 1982-83 season, but on the whole there were slightly fewer mature males. The proportion of mature male fish in late January is very similar for the two years, however. Sample sizes are too small to interpret the February and April results, but it is possible that the percentage of mature males may increase again in these months.

The female data are more difficult to interpret. Even when there are moderately large samples covering the same period (e.g., 15-28 Feb), the proportions of mature fish may vary widely. The proportion of mature female fish in samples fluctuated widely in 1979-80, but it seems to have shown an overall increase between the end of November and the beginning of February and then increased sharply in late February. In 1982-83, there seems to have been a sharp drop throughout November at least, and then a further steady decline throughout the rest of the season. Since

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[1] Percentages of fish that were mature are hereafter referred to as the percentage or proportion of mature fish.

female sample sizes are on the whole low in both seasons, it is difficult to draw any significant conclusions. The observed discrepancy could be due to real differences in the proportion of mature female fish in 178 mm mesh set net catches in each of these two seasons, or it could simply be an artifact of sampling.

When the length, sex and maturity composition data are considered together, it is seen that the composition of 178 mm mesh set net catches changes markedly throughout the season.

Although no data are available for October, nearly all fish caught during early and middle October are mature females (G. Morris, D. Timbrell, pers. comm.). The proportion of males must increase rapidly during late October, however, as by early November, catches appear to consist mainly of mature male fish. This persists throughout November and December. The proportions of mature male and female fish both remain approximately constant over this period. The percentage of mature female fish seems to have decreased markedly during this time in 1982-83.

During January, there is another very large change in the sex composition of catches. While males comprised about 85-90% of the catch during the latter half of December in the two seasons examined, they only comprised approximately 15-30% of the catch during the latter half of January. Although the samples are too small to allow positive conclusions to be drawn, these male fish may be mainly mature.

While female fish are again as dominant in January as they are said to have been in October, it seems that a smaller proportion of mature females are present in January. As noted, however, there are large differences between the two seasons which are difficult to interpret. Nevertheless, about half of the January 1980 females were immature and about 70% of the January 1983 females were immature. Thus, January catches appear to be mainly composed of immature females.

The 178 mm mesh set net catches from February through to the end of the season appear to be almost entirely composed of female fish. During 1980, many of these female fish were mature, but during 1983, the great majority were not fully mature. The differences between these two seasons could be real or they could again be an artifact of sampling. As few samples were taken during this period in either year, it would be unwise to draw any firm conclusions. It is noted, however, that the female fish being caught during these months in 1983 were not small immature fish. Most were about 100-105 cm long and most had just begun maturing.

During the 1982-83 set net season, monthly set net catches were greatest between November and January. In order of decreasing importance, the three most important months were December, January and November. These three months accounted for about 80% of the total set net catch. Furthermore, the November-December period accounted for approximately 55% of the total. The periods before November and after January accounted for approximately 5% and 15% of the total set net catch respectively.

Since the great majority of the set net catch is taken in 178 mm mesh nets, it seems reasonable to use this and the previous data to estimate the overall catch composition of the Pegasus Bay set net fleet in 1982-83. The figures must be regarded as only very approximate, but they are nevertheless useful.

If it is assumed that:

(i) the average proportions of males taken, (1) before November; (2) between November and December, (3) in January, and (4) after January, are 10, 75, 30 and 10% respectively;

(ii) the average percentage of males that are mature in these four periods are 80, 90, 75 and 100% respectively; and

(iii) the average percentage of females that are mature in these four periods are 80, 40, 30 and 20% respectively,

then it is possible to determine the proportion of the total set net catch that was composed of males and the proportion that was composed of females. It is also possible to determine the proportion of each sex that was mature. Finally, it is possible to determine the proportion of the total set net catch that was composed of fish that were male and mature, male and not fully mature, female and mature, and female and not fully mature. These data are shown in Table 4.12.

It is seen from this table that the set net fleet probably took about equal quantities of males and females in 1982-83 season. While approximately 90% of the males were probably mature, only 37% of the females were. The set net part of the fishery appears to be based, therefore, on mature male fish and to a lesser extent, immature and maturing female fish.

Table 4.12 Estimated catch composition of Pegasus Bay set net fleet.

Sex	Catch Composition (%)				
	Total Catch[a]			Each Sex	
	Sex	Immature[b]	Mature	Immature[b]	Mature
M	51	5	46	9	91
F	49	31	18	63	37

[a] Example of how to read 'Total Catch' data: 5% of total set net catch is composed of immature male fish; 51% of total set net catch is male.

[b] Immature defined for this table, as not fully mature.

Too few data are available to quantitatively determine the overall catch composition of the rig fishery. The trawl data are insufficient, and monthly trawl catches are not available. Furthermore, the relative proportions of the total catch taken by trawlers and set nets for the July 1982 - June 1983 year are unknown. Since approximately 70% of the total calendar year rig catch has been taken by set net during the last two years, however, it would seem that the fishery is primarily based on immature and maturing females, and mature males. A significant proportion of the total catch is also likely to consist of immature or maturing males. Very few mature female fish are expected in the catch.

4.5.2 Species' Characteristics

The length-weight regressions reported in section 4.4.1. indicate that the morphometric differences between males and females are significant enough to influence the length-weight relationship. In the samples, small males were heavier than small females of the same length, but weight increased more rapidly with length in the female fish. These results differ from those obtained by Francis (1979).

Since morphometric differences are likely to be greater after sexual maturity, the estimates of the two regression constants will be influenced by the length distributions of the data, relative to the length at maturity. If the female data set contains many immature fish and the male data set contains very few, then the regression constants may not describe the differences between the male and female length-weight relationships accurately. This, I would suggest, is one factor which has led to different results in the two studies. There are marked differences between the distributions of the male and female data points in each of the studies. Furthermore, males and females appear to mature earlier at Kaikoura than in Pegasus Bay. A more detailed analysis would be required to determine the true relationship accurately. It is noted, however, that full-term male and female rig have insignificantly different mean lengths and mean weights in the Pegasus Bay sample. Thus the morphometric differences influencing the relationship probably arise after birth.

Most male rig in the Pegasus Bay region seem to mature between a length of 88 and 90 cm. Very few male rig less than 88 cm long were mature. Over 60% of the 88 cm size class were mature, however, and mature fish comprised at least 80% of the fish in nearly all size classes greater than 89 cm. Only two fish greater than 94 cm in length were not fully mature.

The length at which male rig begin to mature seems to differ considerably between fish. The shortest male that had begun to mature was 77 cm; the longest male that had not begun maturing was 112 cm. The mode of the percentage of maturing fish in each size class, occurred at 84-85 cm. This would seem to be reasonably consistent with the estimate of length at maturity.

Table 4.8 shows that female length at maturity is highly variable. On the whole, however, it appears that most female rig mature at a length of about 106-109 cm. While quite a number of females smaller than this were mature, they did not usually constitute a large percentage of the size class. In contrast, very few fish longer than 109 cm were not fully mature.

The length at which female rig begin maturing also varies. The shortest female that had begun maturing was 92 cm, and the longest female that had not begun maturing was 113 cm. A large number of fish had not begun to mature by the time they were 101-103 cm long. The mode of the percentage of maturing fish in each size class occurs at approximately 103-105 cm. This seems to be reasonably consistent with the estimate of length at maturity.

The estimates obtained for male and female length at maturity in Pegasus Bay differ from those obtained for males and females at Kaikoura and at Nelson. Male rig at Nelson probably mature at less than 82 cm, and Kaikoura males mature at about 85 cm (Francis and Mace, 1980). Females at Nelson are mature at about 85 cm and at Kaikoura they are mature at approximately 95 cm (Francis and Mace, 1980). Thus, length at maturity seems to increase with increasing latitude. It seems to increase more rapidly with latitude in females than in males.

The timing of the reproductive cycle for Pegasus Bay females appears very similar to that for Kaikoura females. Most of the mature females caught in November contained recently ovulated eggs with lesser numbers being in the post-partum or full-term embryo phases. By January, most mature females were in the yolked embryo phase. Some females still contained recently ovulated eggs, however, and some had not yet, or had only recently, given birth. No females contained full-term embryos after January, but some had still not ovulated a new set of eggs by April. Nelson females seem to give birth and mate earlier than either Kaikoura or Pegasus Bay females. While none of the females contained yolked embryos by November at Kaikoura or in Pegasus Bay, 76.2% of Nelson females did.

Although most Pegasus Bay females probably ovulate during spring, it is clear that some females may not ovulate until late summer. It would appear from Table 4.11, however, that this variation is not random. It is unlikely that the observed differences between the size intervals are due to changes in the size distribution of mature female fish throughout the season, as the mean size of females in the November-January and February-April periods did not differ significantly at the 5% level ($t = 1.88$; d.f. = 274; $0.05 < P < 0.1$). Thus, the time of birth and ovulation seems to be progressively later in larger fish. This suggests that the reproductive cycle is a little longer than 12 months. If the gestation period is 11 months (Graham, 1956; Francis and Mace, 1980), then the resting period between pregnancies could be a little longer than four weeks.

Since the gonad index data cover only a short time span, it is impossible to confirm the timing of the female reproductive cycle with information from the male reproductive cycle. If the structure of the male reproductive organs is the same for rig as it is for the two Japanese *Mustelus* species, then the gonad index would be expected to decrease over the summer months. This is not detectable in either Kaikoura or Pegasus Bay fish.

Although the length-fecundity (number of uterine eggs or embryos) relationship for Pegasus Bay females was not able to be calculated, the data do seem to conform closely to the relationship calculated for Kaikoura females. If the observations for females containing full-term embryos[1] are visualised on Figure 4.6, then I believe that it is reasonable to assume that the gradient of the Kaikoura curve would closely approximate that of the Pegasus Bay curve. Since no significant difference was evident between the gradients of the Nelson and Kaikoura curves ($t = 1.878$; d.f. $= 143$; $0.05 < P < 0.1$) (Francis and Mace, 1980), the gradient for the Nelson curve would probably also approximate the gradient of the Pegasus Bay curve. It seems unlikely, however, that the Y-intercept of the Nelson regression line would approximate that of the Pegasus Bay regression line. The Y-intercept of the Kaikoura curve may also be a little higher (though not necessarily significantly higher) than the Y-intercept for the Pegasus Bay curve. These differences (if significant) could very well be due to the differences in female length at maturity noted previously.

It is difficult to draw conclusions on the rates of reproductive failure in Pegasus Bay females during and after ovulation. No baseline reproductive failure data exist for this area, and so it is impossible to determine whether the values obtained are typical of other years. Furthermore, sample sizes are too small to allow valid comparisons with the Nelson and Kaikoura data. The proportion of total reproductive events that are non-yolked appears to be very high, however. The proportion was also high at Kaikoura (13.7%; $n = 615$) and Timaru (12%;

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[1] One 110 cm female contained 2 embryos, one 128 cm female contained 19 embryos, one 130 cm female contained 7 embryos, one 135 cm female contained 24 embryos, and one 136 cm female contained 19 embryos.

$n = 241$) in November and December 1982 (MAF, unpubl. data). M. Francis (pers. comm.) does not remember it being this high at Kaikoura in 1977-79.

As very few females with mid-term embryos were found during the sampling programme, it is difficult to determine the overall rate of embryonic growth. For any one month, however, embryos appear to be of a similar length in Pegasus Bay as at Kaikoura. They are generally much smaller in any one month than the embryos in Nelson females. This is readily explained by the differences in the timing of the reproductive cycle of the two groups of females.

Litters of full-term embryos are not found to contain significantly different proportions of male and female embryos, and the mean lengths and mean weights of viable male and female embryos are also not significantly different in the litters examined. There seems no reason to believe, therefore, that one sex would survive any better than the other after birth. If they are both equally fit in the environment, then juvenile males and juvenile females would be expected to be equally abundant in the population.

5.0 ECONOMIC AND FINANCIAL ANALYSES

5.1 INTRODUCTION

For many years, fisheries management was regarded as a biological discipline (Mitchell, 1979). Management agencies were dominated by biologists, many of whom had little appreciation of the importance of economic considerations and objectives. In hindsight, this seems remarkable, as commercial fishing is actually undertaken for economic reasons. One reason for the dominance of biological objectives in early fisheries management programmes, however, is that the economic theory of fisheries was very late developing. It was not until 1953 that an economic model explaining the underlying causes of excess fishing capacity and over-exploitation in open-access fisheries was formulated.

The simplest model used in fisheries economics is the static economic model. This model was first developed by Gordon (1953) and it is still widely used today.

The model is based on the bell-shaped biological production function which relates the equilibrium yield from a single-species fishery, to the effort applied in that fishery. A simplifying assumption of the model is that the unit price of the fish and the unit cost of fishing effort (including the opportunity costs of the capital and entrepreneurship), remain constant. Thus, the total revenue curve has the same shape as the biological production function, and the total cost curve is a straight line (Anderson, 1977). The long-run relationship between effort, total revenue and total costs is shown in Figure 5.1.

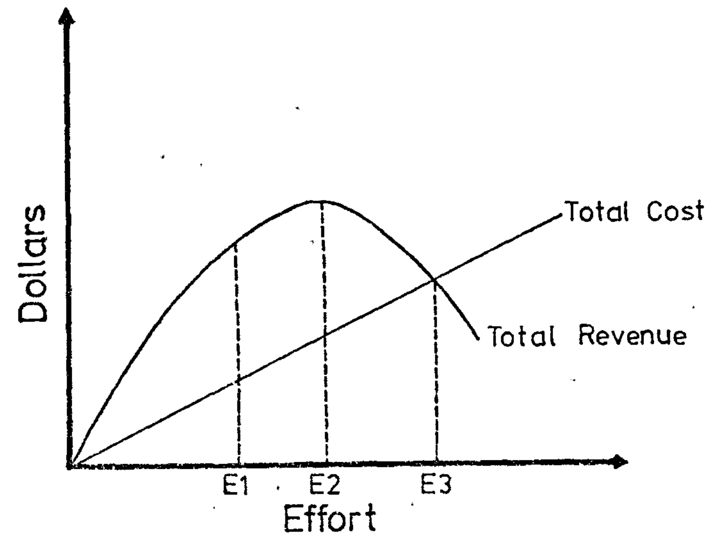

Figure 5.1 Static economic model of a single-species fishery (after Anderson, 1977).

Whenever the total value of a yield is greater than the total costs of harvesting, a fishery will yield a net economic surplus. This surplus is referred to as the resource rent or *economic rent*. The economic optimum occurs, therefore, when the rent is maximised, i.e., at effort E_1 in Figure 5.1. At this level of effort, resources are optimally allocated in the fishery, as the value of the last unit of fish caught, just balances the cost of providing the fish (Anderson, 1977).

In an unregulated fishery, any rent which the fishery yields will accrue to the fishing enterpriser as excess profit (profit over and above the minimum returns to capital and entrepreneurship). If entry is not restricted, these profits will attract new entrants to the fishery. New entrants will continue to be attracted until the earnings from a fishery are no greater than the costs of production. At this point, the fishery reaches what is known as the *bionomic equilibrium*, and all potential rent is dissipated. The fundamental economic problem in fisheries management, therefore, is that whenever a fishery is exploited as common property, any economic rent will induce fishing effort to expand beyond the point required to harvest the resource efficiently and eventually to the point where the fishery is yielding no economic surplus (Pearse, 1980).

Economic assessments of a fishery provide information on resource allocation, individual profitability, and the cost structure of the fishery (Rutherford *et al.*, 1967; Campbell, 1969; Morse, 1971). They can also provide valuable information on the consequences of any management proposal, particularly regarding income maintenance, employment and the distribution of costs and benefits (Ovenden, 1961; Gulland and Robinson, 1973; Crutchfield, 1975; Smith, 1977). The basic data required to undertake an economic assessment of a fishery comes from costs and earnings studies. Costs and earnings studies are, therefore, vital for a more practical understanding of the fishing industry's catching sector (Campbell, 1969).

The costs and earnings analysis presented in this study is similar to recent studies undertaken by the NZFIB (e.g., NZFIB, 1982). The purpose of the analysis is to describe the financial and economic state of the fishery in the 1982-83 season. The financial analysis focuses on the profitability of the fishery, while the economic analysis examines the economic efficiency of the fishery. The costs and earnings data are also used in other parts of the study to examine the implications of some possible management strategies.

5.2 SURVEY METHOD AND RESPONSE

The financial data used in the following analyses were collected through a survey of the commercial set net fishermen late in 1983. The survey is shown in Appendix 4. Since the fishery is small, it was possible to survey the entire fleet. All but one[1] of the set net fishermen who had recorded rig landings on their MAF fishing return forms were, therefore, approached about providing information on their fishing operation.

Most of the surveys were delivered personally. This enabled me to go through the survey with the fishermen to ensure that it was clearly understood. It was also felt that this approach would encourage a higher response rate than if the survey was simply posted out. Personal interviews were not always convenient, however, and so some surveys had to be sent out in the post.

According to MAF records, 30 set net vessels caught rig in Pegasus Bay during the 1982-83 season. Of the 29 fishermen who could be contacted, 20 had the surveys delivered personally and nine received them in the mail.

Altogether, 24 responses were received. This represented 83% of the total survey population. Four of the remaining five fishermen agreed to send in their survey form, but the replies were not received. The response rate for each of the three groups of fishermen identified in section 2.3.3 is summarised in Table 5.1.

Table 5.1 Survey response rate.

Group	Number of Operations		Number of Responses	
	Total population	Survey population	Total	Suitable for analysis
A	5	5	4	4
B	10	10	9	7
C	15	14	11	3
TOTAL	30	29	24	14

[1] This fisherman could not be contacted.

Many of the replies are not able to be used in the analyses as they contain no, or insufficient, financial data. In most cases these replies came from Group C fishermen who did not treat fishing as a financial enterprise. These replies do, nevertheless, yield valuable information on other aspects of the respondent's operation.

The sample size used in the analyses, is regarded as satisfactory in all cases. In Groups A and B, the samples represent 80% and 70% of the total population respectively. Although the sample size is only three in Group C, this represents the majority (60%) of the fishing operations which were actually target fishing for rig, and which were treated as a financial enterprise. The analyses on Group C operations only examine the 'low key' rig fishermen's operations therefore (see section 2.3.3). They will not provide any information on the set net fishermen who did not target fish for rig. Since most Group C fishermen have now been excluded from the fishery as a result of the first national effort reduction step, these analyses are included for interest only.

The data used in the analyses are of variable quality. Some surveys had been filled out very accurately while others had not. The information is still considered to provide a fair indication of each population's overall performance, however, as the data are regarded as being accurate enough for the purposes intended. Furthermore, each of the samples appear to be typical of their respective populations.

5.3 FINANCIAL ANALYSIS

5.3.1 Methodology

All costs and earnings data used in both the financial and economic analyses are sample means. Some of the data (cost data in particular) that each group of fishermen provided, show wide variations from one operation to the next. Wages, for instance, are zero where a partnership arrangement existed, but a major cost in all other operations. For this reason, the mean value of a cost may not be typical of any one of the fishermen's costs. It is simply an 'average' for the group.

Bearing this in mind, the analyses are performed using the following information and assumptions.

(i) Repairs and maintenance

Fishermen were not required to itemise fixed and variable, vessel repair and maintenance costs, separately, on the survey form. The relative proportions of fixed and variable costs for these two expenses are assessed in accordance with NZFIB estimates. For displacement hulls, fixed repairs and maintenance (those on the hull and superstructure) are assumed to represent 33% of the total repairs and maintenance bill. Variable repairs and maintenance (those on the engine and deck machinery) are assumed to account for the remaining 67%. For planing hulls, these expenses are assumed to be 20% fixed, and 80% variable. Net repairs and maintenance (a variable cost) were itemised separately.

(ii) Shore expenses

Shore expenses were probably the most difficult expenses for fishermen to assess. Their estimate should have included such things as onshore vehicle expenses, wharfage, license fees, NZFIB levies, and wholesale handling fees. It should have also included any accountancy or legal fees and telephone bills associated with their fishing operation. These expenses will have almost certainly been underestimated in all of the surveys. Nevertheless, using the estimates provided, shore expenses are assessed at 80% variable (primarily vehicle expenses), and 20% fixed (e.g., administration and wharfage).

(iii) Insurance

This is another cost which varies widely, as not all fishermen had their vessels insured. For Group A operations, the insurance cost is divided between this and the other fisheries which the fishermen participated in, in accordance with the time spent in each fishery. It is assumed that the fishermen spent an average of 14 weeks in the rig fishery during the 1982-83 season. The insurance figure used in the Group A analysis is, therefore, 14/52 of the total annual insurance bill. Group B and C operations have the entire insurance bill charged to the rig season, as these vessels were not used outside this period.

(iv) Interest

The same procedure as was used for insurance is again used in the interest calculations. Group A vessels have the cost split proportionately between the different fisheries, while Group B and Group C operations have the whole bill charged to the rig season.

(v) Depreciation

Depreciation is a measure of the decline in service potential of an asset (NZFIB, 1982). In practice, it is very difficult to actually measure this decline and so depreciation is normally calculated by assuming a fixed rate of decrease in service potential. Each component of a vessel will be subject to different rates of decline, however, and so each component must be depreciated at a different rate. Furthermore, the decline will differ according to the nature of the vessel. Planing hulls generally have a shorter life than displacement hulls, and outboard or stern-drive engines wear much more rapidly than inboard engines, as they rev at much higher rates. Depreciation is calculated on a diminishing value basis, using the figures shown in Table 5.2.

Table 5.2 Depreciation rates of vessel components and nets.

Item	Depreciation Rate (% p.a.)
Hull	
(a) Displacement	10
(b) Planing	20
Engine	
(a) Inboard	20
(b) Outboard and stern-drive	25
Deck machinery	15
Electronic equipment	20
Nets	20

Source: NZFIB, unpubl. data

When assessing the profitability of fishing operations, the historically recorded book values of the vessels and gear are reasonable figures to use for depreciation purposes (S. Andrews, pers. comm.).

Thus, depreciation calculations are based on the purchase value of the vessel and gear. Since the hulls, engine, deck machinery and electrical equipment depreciate at different rates, it is necessary to ascribe a fixed proportion of the vessel's purchase value to each of these four components. Once again, the proportion varies with the nature of the vessel. The figures used are based on NZFIB estimates. These figures are shown in Table 5.3.

Table 5.3 Percentage of vessel's purchase value, attributable to each vessel component.

Vessel Component	Percentage of Vessel's Purchase Value	
	Displacement hull vessels	Planing hull vessels
Hull	45	40
Engine	15	40
Deck machinery	20	15
Electronic equipment	20	5

Source: NZFIB, unpubl. data

Where an engine had been replaced since the vessel was purchased, engine depreciation calculations are based on the purchase value of the new engine. Purchase values for gear were independently itemised in the survey. Since most fishermen had some old nets and some new nets, however, it is necessary to assume that the gear had a mean age of two years.

Group A operations again only have 14/52 of the total depreciation charged to the rig season, while Group B and Group C vessels have the entire amount charged. All depreciation of Group A gear is, however, included in the analyses, as this gear is not used outside the rig season.

5.3.2 Profitability

Tables 5.4, 5.5 and 5.6 show the results of the three group analyses. It should be stressed that these figures are the average costs and earnings

Table 5.4 Financial analysis of group A operations[a].

	GROSS ($)	PERCENTAGE OF GROSS EARNINGS
TOTAL SALES	**21,030**	**100.0**
COSTS		
A. Variable Costs		
(a) Wages	2050	9.7
(b) Fuel and oil	3180	15.1
(c) Variable repairs and maintenance		
(i) Engine and deck machinery	1090	5.2
(ii) Nets	1630	7.8
(d) Variable shore expenses	1340	6.3
TOTAL VARIABLE COSTS:	9290	44.2
CONTRIBUTION MARGIN:	11,740	55.8
B. Fixed Costs		
(a) Insurance	700	3.3
(b) Interest	620	2.9
(c) Fixed repairs and maintenance	550	2.6
(d) Fixed shore expenses	340	1.6
TOTAL CASH FIXED COSTS	2210	10.5
TOTAL CASH COSTS	11,500	54.7
CASH SURPLUS	9530	45.3
(e) Depreciation		
(i) Vessel	2000	9.5
(ii) Nets	700	3.7
TOTAL FIXED COSTS	4980	23.7
TOTAL COSTS	**14,270**	**67.9**
NET INCOME	**6760**	**32.1**

[a] Sample size: 4 Percentage of group population: 80

Table 5.5 Financial analysis of Group B operations[a].

	GROSS ($)	PERCENTAGE OF GROSS EARNINGS
TOTAL SALES	**27,810**	**100.0**
COSTS		
A. Variable Costs		
(a) Wages	2690	9.7
(b) Fuel and oil	6510	23.4
(c) Variable repairs and maintenance		
(i) Engine and deck machinery	3400	12.2
(ii) Nets	1970	7.1
(d) Variable shore expenses	1630	5.9
TOTAL VARIABLE COSTS	16,200	58.3
CONTRIBUTION MARGIN	11,610	41.7
B. Fixed Costs		
(a) Insurance	490	1.8
(b) Interest	1790	6.4
(c) Fixed repairs and maintenance	850	3.1
(d) Fixed shore expenses	410	1.5
TOTAL CASH FIXED COSTS	3140	11.3
TOTAL CASH COSTS	19,340	69.5
CASH SURPLUS	8470	30.5
(e) Depreciation		
(i) Vessel	5000	18.0
(ii) Nets	1130	4.0
TOTAL FIXED COSTS	9270	91.6
TOTAL COSTS	**25,470**	**91.6**
NET INCOME	**2340**	**8.4**

a Sample size: 7 Percentage of group population: 70

Table 5.6 Financial analysis of Group C operations[a].

	GROSS ($)	PERCENTAGE OF GROSS EARNINGS
TOTAL SALES	**1870**	**100.0**
COSTS		
A. Variable Costs		
(a) Wages	160	8.6
(b) Fuel and oil	1150	61.5
(c) Variable repairs and maintenance		
(i) Engine and deck machinery	170	9.1
(ii) Nets	410	21.9
(d) Variable shore expenses	120	6.4
TOTAL VARIABLE COSTS	2010	107.5
CONTRIBUTION MARGIN	- 140	- 7.5
B. Fixed Costs		
(a) Insurance	120	6.4
(b) Interest	130	0.2
(c) Fixed repairs and maintenance	40	6.9
(d) Fixed shore expenses	30	1.6
TOTAL CASH FIXED COSTS	320	17.1
TOTAL CASH COSTS	2330	124.6
CASH SURPLUS	- 460	-24.6
(e) Depreciation		
(i) Vessel	670	35.8
(ii) Nets	140	7.5
TOTAL FIXED COSTS	1130	60.4
TOTAL COSTS	**3140**	**167.9**
NET INCOME	**-1270**	**-67.9**

[a] Sample size: 3 Percentage of group population: 60

per operation, and not per owner, as some of the operations are partnership owner-operated.

The contribution margin is the average amount of money that remains out of gross earnings after all variable expenses have been paid. Expressed as a percentage, it represents the average number of cents in each dollar of sales, which is available to meet fixed costs and provide an income to the owner(s) of the operation.

Total fixed costs are equal to the total cash fixed cost, plus depreciation.

Net income is the average net income to an operation before tax.

5.3.3 Break-Even Analysis

One very useful way of summarising the financial viability of this fishery for each group of fishermen is to calculate an income equation for each group. These equations also provide a ready basis for inter-group comparisons, as they highlight the financial differences which existed between the three groups.

An income equation is a linear function of the format,

$$Y = MX - C \quad \text{(NZFIB, 1982)} \tag{5.1}$$

where,

Y = net income before tax,
M = contribution margin,
X = gross revenue, and
C = total fixed costs.

Using the information in section 5.3.2, the income equations for each group are:

$$Y_A = 0.56X_A - 4980 \tag{5.2}$$

$$Y_B = 0.42X_B - 9270 \tag{5.3}$$

$$Y_C = 0.08X_C - 1130 \tag{5.4}$$

These equations are shown in Figure 5.2.

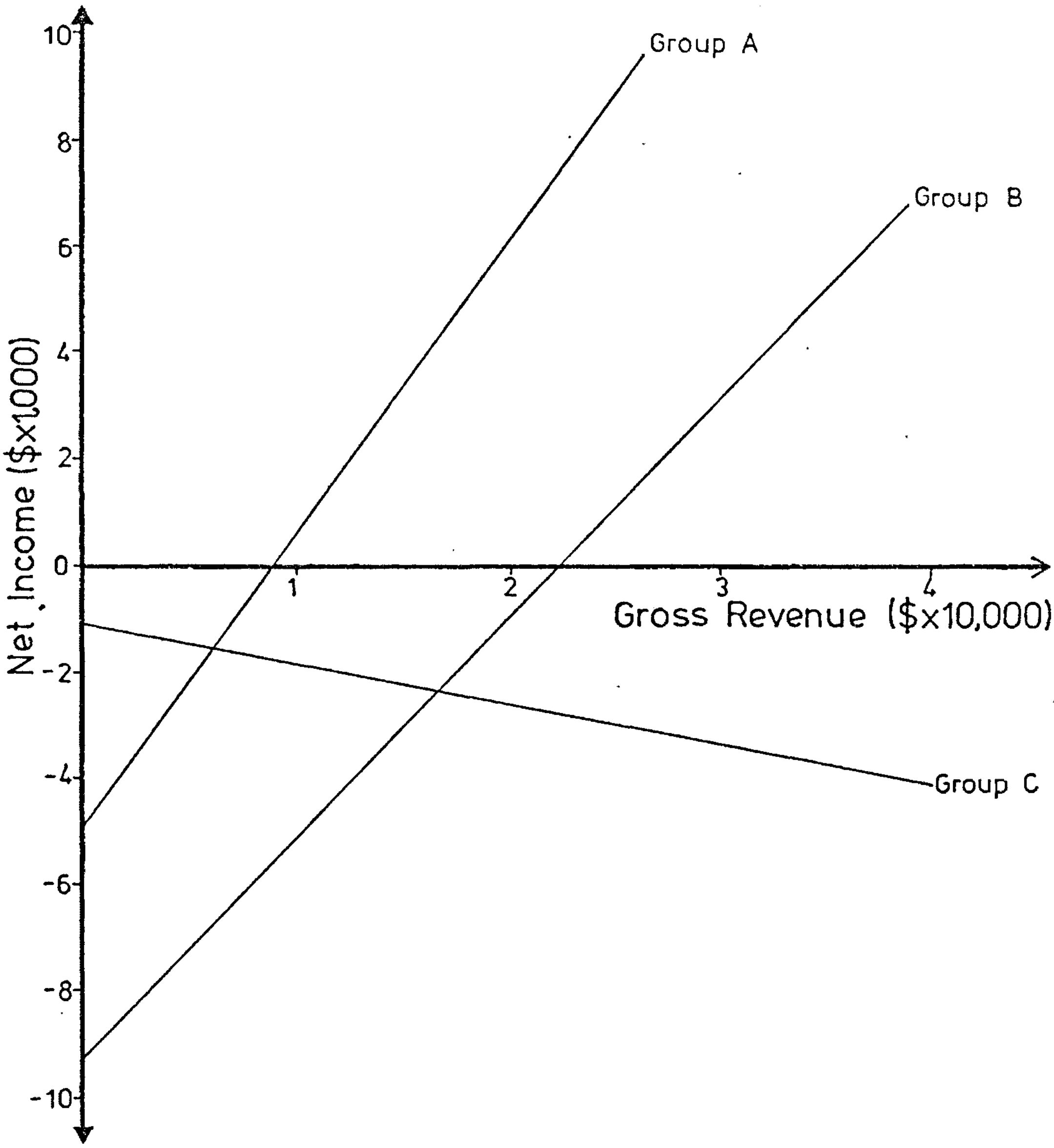

Figure 5.2 Gross revenue - net income relationship for each group of Pegasus Bay rig fishermen.

By equating Y with zero and solving the income equations for X, it is possible to determine how much revenue the average operation in each group needed to earn to cover all costs (excluding the cost of each owner's labour). The required revenue for each average operation was:

Group A :	$8890
Group B :	$22, 070
Group C :	no solution.

An important assumption of these calculations is that net income was linearly related to gross earnings, over the zero to break-even revenue range.

5.3.4 Costs, Revenue and Net Income Per Unit of Catch and Effort

Although the profitability information on each of the three groups of fishermen is very useful, it does not describe the economics of this fishery very well by itself. The reason for this is that it does not provide any information on the efficiency with which each group caught their fish. To complete the financial analysis, therefore, it is necessary to examine the costs, revenue and net income per unit of catch, and per unit of effort.

The catch and effort data used in this analysis were obtained from MAF statistical return forms. A list of the vessels included in the profitability calculations was sent to the MAF, and the Ministry then returned figures for the mean catch and effort of each group of vessels.

One major problem with this type of analysis is that the catch and effort data provided by fishermen are notoriously unreliable. This must be recognised when doing the calculations and when interpreting the results. To eliminate as much error as possible, an estimate of each vessel's catch (based on the gross earnings figures provided) was also included on the list sent to the MAF. Where wide discrepancies exist between the estimated and recorded catches, the vessel is eliminated from the sample for this part of the analysis. This reduces the sample sizes to three in Group A, four in Group B, and three in Group C. The analysis is performed, only using the costs and earnings data of the operations included in the mean catch and effort calculations, rather than the overall figures presented in section 5.3.2. The samples used in this analysis are considered to be representative of the samples used in section 5.3.2, as the mean costs and earnings data of these operations correspond very closely with the mean costs and earnings data presented in Tables 5.4, 5.5 and 5.6.

It is worth stressing that the analyses in this study only describe a very dynamic economic system in static terms. They cannot describe past economic trends in the fishery and so can give misleading results if the season being examined is atypical of previous seasons or prevailing trends. This is particularly true of analyses which use catch data directly, as the catch may fluctuate widely from one year to the next, even when effort remains relatively constant.

A. Costs, revenue and net income per unit of catch

The costs, revenue and net income per unit of catch data are shown in Table 5.7. Net income per unit of catch is defined as the untaxed mean net income to an operation, per tonne of fish landed. The variable revenue per tonne values resulted from different species composition of the three catches.

Table 5.7 Costs, revenue and net income per unit of catch.

		Dollars per Tonne of Fish Landed			
			Costs		
Group	Mean Catch (t)	Revenue	Variable	Total	Net Income
A	6.71	2930	1420	2040	890
B	12.89	2480	1520	2300	180
C	0.87	2150	2310	3610	-1470

B. Costs, revenue and net income per unit of effort

The effort unit used in this section differs from that used in chapter 3, as the latter would have resulted in a serious bias if used in this analysis. In chapter 3 the unit used is 100 m days, days being the number of days that fish was landed. For Group B and Group C operations, the number of days that fish was landed is equivalent to the number of days fished, as these fishermen only made one-day fishing trips. Three of the four Group A fishermen, however, remained at sea for periods of 2-4 days. Relative to Group B and C's effort, therefore, Group A's effort will be grossly underestimated by this unit. To correct for this bias, effort has been measured in units of 100 m days-fished. For the three Group A fishermen who remained at sea for more than one day, 100 m days-fished is calculated by assuming a mean trip length of first two days, and then three. Each of these fishermen's effort is then added to the fourth fisherman's effort (mean trip length of one day) to obtain the overall effort for that group as shown.

Table 5.8 shows the cost, revenue and net income per unit of effort data. Net income per unit of effort is defined as the untaxed mean net income per 100 m days-fished.

Table 5.8 Costs, revenue and net income per unit of effort.

Group	Mean Effort (100 m days-fished)	Dollars per 100 m Days-fished			
		Revenue	Costs Variable	Costs Total	Net Income
A (a) 2-day trips[a]	850	23.1	11.2	16.1	7.0
(b) 3-day trips[b]	1240	15.9	7.7	11.1	4.8
B	880	36.3	22.4	33.7	2.6
C	140	13.0	14.0	21.9	-8.9

[a] Mean trip length of two days for the three vessels which spent more than one day at sea per trip.

[b] Mean trip length of three days for these three vessels.

5.3.5 Returns to Capital and Entrepreneurship

The net income which an operation earns provides a return to each owner's capital, labour and management skills. In practice, it is difficult to determine what proportion of the remaining net income should accrue to labour, and what proportion should accrue to management skills, after the return to capital has been accounted for. These two variables are aggregated, therefore. The net income which remains after the return to capital has been accounted for, is termed a return to entrepreneurship.

The returns to capital and entrepreneurship which fishermen obtain determine how viable fishing is as a means of earning a living. The current viability of the fishery is assessed using present returns to capital and entrepreneurship. Book values of the capital are reasonable figures to use when assessing the current viability of the fishery (S. Andrews, pers. comm.).

It is also important to assess the long-term viability of a fishery. The only realistic value of assets to use when assessing the long-term viability of a fishery is the replacement value of the assets (NZFIB, 1979).

An important assumption of any assessment of future viability is that the earnings and variable costs remain the same with the new vessel. Some fixed costs (insurance, interest and depreciation) will change, however. In the analysis which follows, depreciation is calculated in the same manner as described in section 5.4.1. Insurance costs are assumed to equal 3.5% of the vessel's replacement value, as in NZFIB (1979). Only those vessels which were insured for the last season are charged with an insurance cost. Interest is not included in the fixed costs for this part of the analysis, as the terms of these loans will vary widely from one operation to the next. Net income is, therefore, net income before interest and tax for this part of the analysis.

A. Return to entrepreneurship

For the purposes of this analysis, a 'reasonable' return to capital is conservatively estimated at 10% per annum. This is considered to be the minimum return that is necessary to retain investment in the industry in the short-term (NAFMAC, Anon). It is noted, however, that this is probably insufficient to prevent disinvestment in a fishery (through the non-replacement of assets as they wear out) in the longer term (NAFMAC, Anon).

Since Group A vessels were used in other fisheries outside the rig season, it is necessary to apportion the total annual return to capital between the different fisheries. This is done by making the same assumption here as is used in the insurance, interest and depreciation calculations, i.e., that Group A fishermen spent 14 weeks set netting for rig.

All figures presented in the financial analyses so far represent the costs, earnings or net income to an operation. It is felt that the most appropriate figure to calculate in this section is the return to *each owner's* entrepreneurship. This is done by subtracting the return to capital from each operation's net income, and then dividing the resulting return to entrepreneurship by the number of fishermen who owned the operation. The mean return to entrepreneurship is then computed by taking the mean of all the individual returns. These data are shown in Table 5.9.

B. Return to capital

In this part of the analysis, the average New Zealand wage ($15,000 p.a.) is used to represent a 'reasonable' return on each owner's entrepreneurship. In view of the risks and lifestyle associated with fishing, this is also regarded as being a very conservative figure. It is probably the minimum return that is necessary to retain employment in the fishery in the long term (NAFMAC, Anon). It is assumed that Group A and Group B fishermen each spent an average of 14 weeks set netting for rig during the season, and that none of them had other employment as well during this period. Thus, the appropriate return to entrepreneurship for the 14 week period is $4038 per owner. Group C fishermen are assumed to have spent an average of 20% of their working hours fishing for rig during the season. Information obtained from these fishermen suggests that this estimate is probably conservatively low. For these fishermen, therefore, the appropriate return to entrepreneurship is $808 per owner.

The return to capital is calculated by simply taking the mean of all the *owner's* returns to capital. Each owner's return to capital is computed by subtracting his return to entrepreneurship from his share of the operation's net income. The results of these calculations are shown in Table 5.9.

C. Viability

The current and long-term viability of the fishery is assessed by calculating the mean 'excess' net income *per owner* for each group. 'Excess' net income per owner is defined as the net income remaining after an owner's minimum reasonable returns to capital and entrepreneurship have been subtracted from his actual net income. Each owner's net income and reasonable return to capital are computed by dividing those of the operation by the number of owners. The mean excess net income is then calculated by taking the mean of all individual figures for each group. These data are shown in Table 5.9. Table 5.10 shows the percentage of owners in each group which were breaking even, attaining a positive return to entrepreneurship and obtaining a positive excess net income, using both the book and replacement values of their assets.

5.4 ECONOMIC ANALYSIS

5.4.1 Capitalisation in the Catching Sector

Several measures may be used to estimate the capital invested in the catching sector of a fishery. These are the book value, the market value, and the replacement value of the vessels and fishing gear. Since the economist's concern is to ensure an efficient allocation of resources between alternative uses, the most appropriate measure is the current economic value of the capital, i.e., market values. Book values do not provide a good estimate of the capital invested as the vessels and gear are depreciated in accordance with the rules set for taxation, rather than market values. Replacement values overestimate the value of the vessels and gear actually employed in the fishery.

Unfortunately, it is very difficult to estimate market values at present as the permit moratorium has had considerable impact on vessel sales. However, the market values of most vessels and gear will probably fall between the book and replacement values. The book and replacement values may be used, therefore, to provide an indication of the level of capitalisation in the catching sector.

While book values may be determined relatively easily, it is frequently difficult to obtain an accurate estimate of the replacement value of a vessel. The estimates used were obtained from fishermen in

Table 5.9 Returns to capital and entrepreneurship per owner, and 'excess' net income per owner.

Group	Net Income per Owner		Return to Capital or Entrepreneurship per Owner ($)				'Excess' Net Income per Owner ($)	
			Current		Long-term			
	Current	Long-term	Capit.	Entrepr.	Capit.	Entrepr.	Current	Long-term
A	3450	1240	-590	2860	-2370	-660	-1180	-4700
B	1500	-1550	-2540	-270	-5590	-5310	-4310	-9710
C	-1280	-4800	-2090	-1610	-5600	-6910	-2420	-7720
TOTAL	1690	-1160	-1810	550	-4520	-3310	-2950	-7710

Table 5.10 Distribution of individual returns to capital and entrepreneurship, and 'excess' net income.

Group	Percentage of Owners in each Group Sample					
	Book value			Replacement value		
	Breaking even	Positive return to entrepr.	Positive excess net income	Breaking even	Positive return to entrepr.	Positive excess net income
A	100	100	17	50	17	17
B	57	43	33	43	29	29
C	33	33	0	0	0	0
TOTAL	67	61	22	39	17	17

the survey. When the estimated replacement values of similar vessels are compared, it is found that the estimates are always very compatible. It is assumed, therefore, that the estimates are realistic. Replacement values for gear are much easier to assess as current prices are readily available to check estimated values against. Where replacement value data are not available for all the vessels and gear in a group, total values are calculated by assuming that the missing vessels and gear have a replacement value equal to that of the sample mean.

Table 5.11 shows the total estimated book and replacement values of the capital invested in the catching sector of the fishery in the 1982-83 season. Trawlers and those Group C vessels which did not target fish for rig, are not included in the estimates. These vessels only took rig as a by-catch and are not considered to have been sufficiently involved in the fishery to warrant inclusion in the estimates.

Group B operations and those Group C operations included in Table 5.11, were only active during the rig season. In contrast, Group A operations were active all year. Group A operations did not set net outside the rig season, however. Thus, the capital associated with Group B operations, those Group C operations included in the table, and Group A operations' gear, is invested in the rig fishery only. The capital associated with Group A vessels is invested in other fisheries at other times of the year.

5.4.2 Economic Rent

It is impossible in this study to obtain an accurate estimate of how much economic rent the fishery was yielding in the 1982-83 season, as not all the required data are available. Nevertheless, it is still useful to provide an indication of what the rent was.

Economic rent is defined in section 5.1 as the difference between the economic costs of harvesting a resource, and the economic benefits which the resource yields. Since all fish caught by the set net fishermen was sold competitively, it is assumed in this analysis that the benefits of the fish were equal to the consumers' willingness to pay. Thus, the economic benefit was equal to the gross revenue of all operations.

Table 5.11 Estimated capitalisation in the catching sector of the Pegasus Bay rig fishery.

Group	Number of operations		Capital Invested ($ x 1000)					
			Book value of population			Replacement value of population		
	Population	Sample	Vessels	Gear	Total	Vessels	Gear	Total
A	5	4	148	16	164	610	39	649
B	10	9	183	45	228	447	82	529
C	5	4	11	2	13	83	8	91
TOTAL	20	17	342	63	405	1140	129	1269

The economic costs of the inputs used to harvest the fish are more difficult to quantify. If the economic cost is assumed to be equal to the opportunity cost of the inputs, then the market price will approximate the economic cost of many of the inputs (Anderson, 1977). Market prices may be subject to either taxes or subsidies, however. Taxes are not economic costs, but subsidies are (Gittinger, 1972). Thus, the true economic cost will be equal to the market value of the inputs, plus any subsidies and less any taxes. Without detailed information, the true economic costs cannot be determined.

For the purposes of this analysis, the costs of the inputs are assumed to be equal to the sum of:

(i) all financial costs, with the exception of depreciation and interest;

(ii) the opportunity cost of all owners' entrepreneurship; and

(iii) the opportunity cost of all owners' capital.

Interest is not included as it is part of the total return to capital, available to society as a whole (Gittinger, 1972). Depreciation is not included as it is simply a financial book payment which transfers funds from fixed assets to current assets (Bannock *et al.*, 1977). Neither interest nor depreciation are economic costs, therefore. The opportunity cost of the owner's capital and entrepreneurship are assessed using the same assumptions as were used to estimate minimum reasonable returns to capital and entrepreneurship in section 5.3.5.

The economic rent is calculated as the rent yielded by the total population of set net fishermen (excluding those Group C fishermen which do not target fish for rig). Operations which are not included in the financial analyses are assumed to have had costs and earnings equai to that of the mean of their respective groups. Since market values of the vessels and gear are difficult to assess at present, the economic rent is calculated using, first, the book values of the assets, and then the replacement values of the assets. Rent is then expressed as a percentage of total costs. These data are shown in Table 5.12.

Table 5.12 Economic rent yielded by total population of set net fishermen[a].

Group	Total Revenue ($)	Total Cost ($)		Economic Rent			
				Book value		Replacement value	
		Book value	Repl. value	Gross ($)	Percentage	Gross ($)	Percentage
A	105,150	87,080	100,150	18,070	20.8	5,000	5.0
B	278,100	250,780	280,970	27,320	10.9	-2,870	-1.0
C	9,350	16,690	25,600	-7,340	-44.0	-16,250	-63.5
TOTAL	392,600	354,550	406,720	38,050	10.7	-14,120	-3.5

[a] Excluding Group C fishermen who do not target fish for rig.

5.5 DISCUSSION

5.5.1 Financial Analysis

The profitability analysis shows that Group A was clearly the most profitable group of fishermen in the 1982-83 season. Although their gross earnings were considerably less than Group B's, their total costs were only half as high. Consequently, Group A's net income was nearly three times higher than Group B's. It is notable, however, that the two groups had similar contribution margins and cash surpluses.

Group A operations also appear to have been in a more sound financial position than Group B operations. This does not necessarily follow from greater gross profitability, but it does indeed appear to be the case in this fishery. The net income per dollar invested and net income per dollar of sales, two indicators of financial strength, were both much higher for Group A operations than Group B operations. This will have placed Group A operations in a much better position to service their debts and earn a living than Group B operations.

Another good way of examining financial strength is to express net income as a percentage of liabilities. Since no information was obtained on liabilities in the survey, it is not possible to examine this quantitatively. If interest is taken as an indicator of liabilities, however, it seems likely that net income would have been a much higher percentage of liabilities for Group A operations than Group B operations. This will have again placed Group A in a much better position to service their debts and earn a living than Group B operations.

On the whole, Group B operations appear to have been in a rather precarious position. They caught a large quantity of fish (relative to either of the other groups), but only earned a very small net income. This is because their costs were so high. Costs accounted for 92 cents in every dollar of sales compared to 68 cents in every dollar of sales for Group A. The average Group B operation would, therefore, be very vulnerable to even comparatively small increases in costs (e.g., fuel) or alternatively, to comparatively small decreases in catch. Either of these events could have a serious impact on their net income.

Group C operations were obviously in a very unenviable position. Overall, they were running at a substantial loss, as their total costs were 68% higher than their gross earnings. Even their cash surplus was negative. The income equations show that it was impossible for the average Group C to even cover his costs.

Most of Group A and Group B's costs accounted for very similar proportions of the total revenue. The major cost structure differences between the two groups existed in the fuel and oil, maintenance, interest, and depreciation costs. These costs consumed a much higher percentage of the revenue for Group B operations than Group A operations. Since Group A vessels ran on diesel, and since most of the vessels remained at sea for 2-3 days, they naturally had much lower fuel costs for each day's fishing than Group B vessels, which ran on petrol and returned to shore each evening. Group B vessels also wear much more rapidly, as the engines rev at much higher rates. This incurred higher maintenance costs. Although Group A vessels had a higher mean purchase value than Group B vessels, interest and depreciation costs were considerably less for Group A operations. The reason for this is that Group A operations had these costs spread throughout the year, while Group B operations bore them all during the rig season. Furthermore, depreciation rates are higher on Group B vessels for the reasons noted in section 5.4.1.

Several differences are also found to exist between Group A and Group B with regard to the efficiency with which they caught their fish. While the costs and revenue per tonne of fish landed did not differ greatly, Group A's net income per tonne of fish landed was nearly five times higher than Group B's.

The costs and revenue per unit of effort reveal more marked differences between the two groups. Group B's revenue per unit of effort was considerably higher than Group A's, but so too were its costs per unit of effort. This resulted in a much higher net income per unit of effort for Group A operations than Group B operations, even when the mean trip length was assumed to be three days rather than two. Group C again fared very poorly. It had the highest costs per tonne of fish landed, the lowest net income per tonne of fish landed, and the lowest net income per unit effort of any of the groups.

The financial viability of each group is assessed in section 5.3.5 by comparing the returns to capital and entrepreneurship which the average owner in each group attained, with estimated minimum reasonable returns.

These minimum reasonable returns represent the returns which an owner could expect to earn if he employed his capital and entrepreneurship in other financial ventures.

Table 5.9 shows that although Group A operations were, on the whole, the most profitable, not even they were obtaining the minimum reasonable returns to capital and entrepreneurship. To provide returns equivalent to those which (it is assumed) the average Group A owner could have earned through alternative use of his capital and entrepreneurship resources, the average Group A operator would have needed to increase his net income by approximately 35%. Net income per owner would need to have been nearly three times higher to provide minimum reasonable returns to the average Group B operator. Since the total costs for Group C operations were considerably higher than total revenue, the average Group C owner was unable to make his operation viable. The best that he could have done was to minimise his losses. This would have been done by not fishing (see Figure 5.2).

It would appear, therefore, that the average owner in all three groups earned considerably less from having his resources invested in a fishing operation than he is assumed to have been capable of earning from another financial venture. While some individuals in Groups A and B did earn minimum reasonable returns to their capital and entrepreneurship (see Table 5.10), the majority earned substantially less. It is very unlikely that most operations earned sufficient net income during the season, to even provide the owners with a satisfactory wage. The average Group B net income of $1500 is very little for three months' work, and even the average Group A net income ($3500) is less than the average New Zealand wage for the same three month period. In view of the risks and lifestyle associated with fishing, these returns are very poor.

Since the great majority of vessel owners were not attaining reasonable returns on their capital and entrepreneurship, it is clear that they were earning less than is required to make the fishery viable for them in the long-term. To assess the long-term viability of a fishery, it is necessary to base cost and return to capital estimates on the replacement value of each operation's assets. When this is done, it is found that the average Group B and Group C owner did not even cover his costs. While the average Group A owner did, he was only earning approximately one-fifth of the estimated minimum reasonable return to capital and entrepreneurship.

Overall, therefore, very few fishermen were earning sufficient net income to provide themselves with reasonable returns to their capital and entrepreneurship in the long-term (see Table 5.10).

5.5.2 Economic Analysis

The results presented in section 5.4.2 indicate that the fishery is also in a very dismal economic state. The amount of economic rent which the fishery yielded in the 1982-83 season cannot be determined precisely, but it is very likely that the actual amount lay somewhere between the two estimates provided. Theory suggests that if the economic rent was zero, or very close to it as indicated, then the net economic yield from this fishery could be increased greatly by reducing effort and redeploying the "freed" resources into other sectors of the economy.

Since the rig population is almost certainly declining (see section 3.4), it seems reasonable to assume that the population has not reached equilibrium size, for the level of effort that is being applied. At present, therefore, the revenue from this fishery would appear to be above the long-run equilibrium revenue point. The exact location of this equilibrium point depends on what the equilibrium population size is for the effort currently being applied. Two possibilities exist: the equilibrium population size could be between the maximum and zero, or it could be equal to zero. Thus, the fishery will be described by one of the two points (E_1, TR_1 or E_2, TR_2) shown in Figure 5.3.

While the economic rent from this fishery was probably very close to zero in the 1982-83 season, Figure 5.3 indicates that this is not a stable long-run situation. In the long-term, the rent will decrease even further if costs and effort remain the same, regardless of which of the two points the fishery is presently at. It seems likely, therefore, that if costs and effort do remain the same, the fishery will soon generate significant economic losses.

In summary, it appears that the fishery is in a very serious financial and economic state. Very few fishermen are obtaining minimum reasonable returns to their capital and entrepreneurship and, for most, fishing cannot be viable in the long-term given present costs and earnings.

From an economic standpoint, the fishery is operating very inefficiently, implying that it is heavily over-capitalised. In the long-run, it is expected that the fishery will incur significant losses to the economy if costs and effort remain the same.

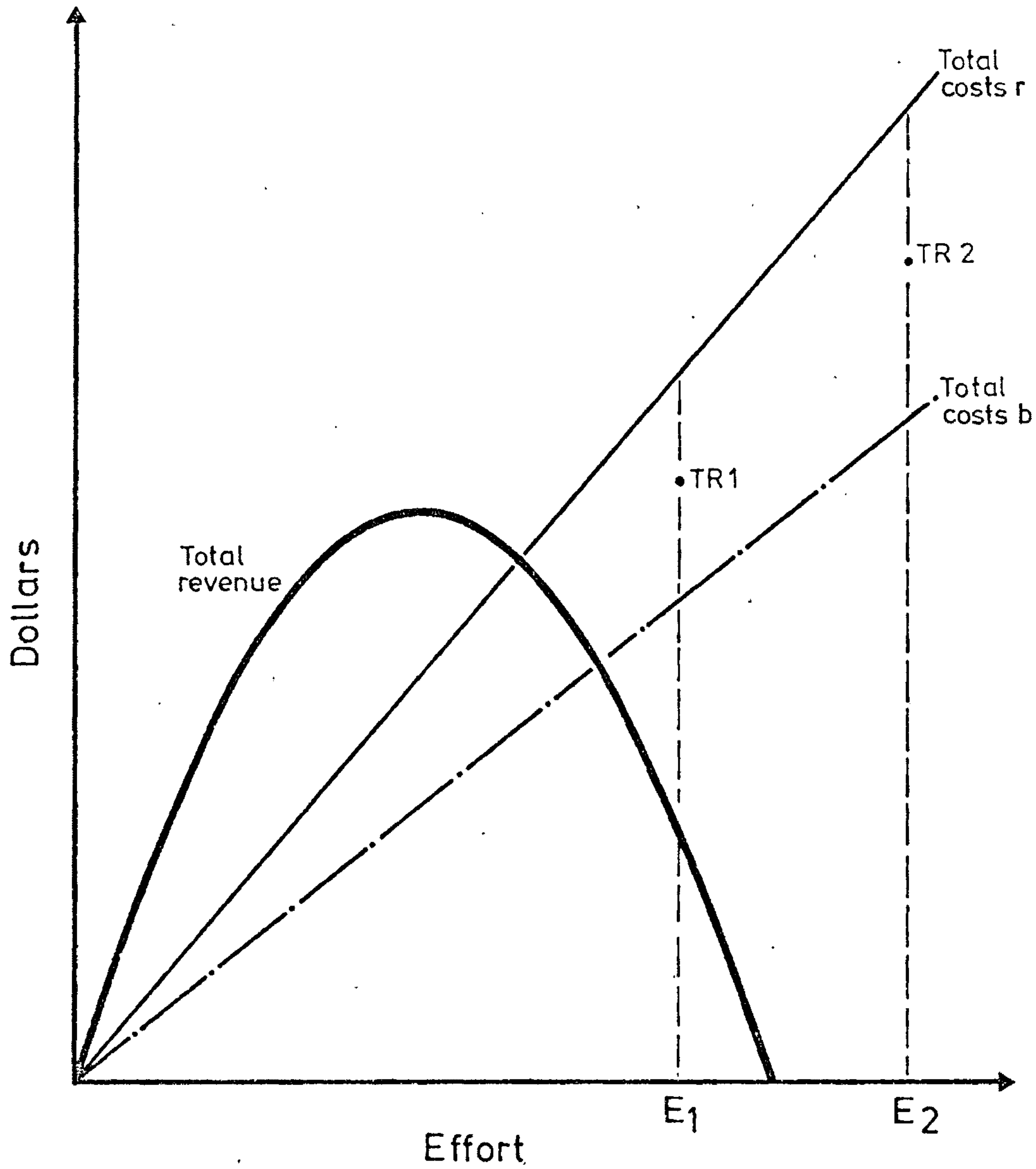

Figure 5.3 Diagrammatic representation of the economic state of the Pegasus Bay rig fishery. Total costs r and Total costs b are total costs based on the replacement and book value respectively of the operation. TR1 and TR2 are above the maximum on the Total revenue curve for reasons which are explained in section 6.3.

6.0 MANAGEMENT

6.1 OPTIMUM YIELD AS A MANAGEMENT GOAL

6.1.1 Reason for Adopting the Goal

New Zealand's fish resources are public property. They belong to the nation as a whole and so no one individual or group has any greater claim to them than another.

This may seem to be a statement of the obvious, but the point is an important one as it provides the key to what I believe must be the goal of fisheries management. It tells us that because the resources belong to the entire public, then they must be developed and managed for the greatest possible benefit of the entire New Zealand public. Since the individuals associated with the fishing industry constitute only part of the public, management cannot cater for their interests alone. It must also account for other sectors' interests and for general societal goals and objectives. It would seem to be only right that this principle is adopted to guide management as,

> *"... [the] taxpayers not only own ... [the] fisheries resources but they [also] pay the cost of maintaining these resources for the benefit of existing and future generations."*
>
> (Sinclair, 1978)

It should be pointed out that society also pays the opportunity cost of sacrificing the resource and the potential benefits it offers, if a resource is not managed for the greatest benefit of the public.

In my opinion, there is only one goal which can be used to manage fisheries for maximum public benefit: optimum yield. This goal is broad enough and flexible enough to allow managers to address every possible element of public benefit. Furthermore, it makes no assumptions about the importance of the different elements. Biological, economic, social and political values (and any other important values) are all equally integral components of the optimum yield. All other management goals (e.g., maximum sustainable yield, maximum economic yield) fail to address any more than two sets of values. Not only does this exclude the possibility of deliberately managing for other values, but it assumes that the chosen values are more important than others. Optimum yield also provides a framework for resolving conflicts which arise between incompatible objectives.

Other goals do not. They seek mathematical solutions to social phenomena. If the task is to manage fisheries for the greatest possible benefit of the public, then in my opinion it is both logical and necessary to regard optimum yield as the management goal.

The penalty for accepting this goal is that managing fisheries becomes exceedingly complex. No longer is it simply a matter of conserving a fish stock, maximising the yield or protecting the livelihood of fishermen. Instead, we are faced with a truly multifarious array of conflicting objectives. The difficulty in resolving these conflicts is, however, no justification for reverting to single-objective management functions. While the objectives may be made to disappear, the responsibility cannot.

Section 4 of the Fisheries Act (1983) states that the purpose of a fishery management plan is to,

> "... *conserve, enhance, protect, allocate and manage the fishery resources within New Zealand fisheries waters having regard to the need for -*
>
> *(a) planning, managing, controlling and implementing such measures as may be necessary to achieve those purposes;*
>
> *(b) promoting and developing commercial and recreational fishing;*
>
> *(c) providing for optimum yields from any fishery and maintaining the quality of the yield without detrimentally affecting the fishery habitat and environment.*"

"Optimum" is defined in the act as,

> "... *the maximum sustainable yield from that fishery modified, for the purposes of a management plan, by any relevant economic, social, recreational, or ecological factor.*"

The definition of "optimum" used in the act is, I believe, broad enough to include all of the factors stated in Section 4. Conservation, allocation, maintaining the quality of the yield and all the other factors listed in Section 4 are all relevant to management of a fishery and so I believe that they are all elements of the optimum yield. It is very useful, therefore, to consider optimum yield as the foundation concept in fisheries management planning.

6.1.2 Interpretting the Goal

The inclusion of the words "optimum yield" in the act is, in my opinion, very pleasing. Their inclusion offers fisheries management planners ample potential to manage New Zealand's fish resources for maximum public benefit and, therefore, to improve utilisation and management of the resources dramatically. By itself, however, the term is too vague to guide planners effectively. If fisheries management planning is going to be as successful as everyone hopes, then it will be necessary to interpret the term; to give it meaning. Without such an interpretation, the act is merely paying lip service to a popular concept.

At present, no such interpretation is included in the act. The First Schedule contains a list of factors which must be included in the plan, but this list does not provide any assistance in determining how, for instance, the maximum sustainable yield should be modified to achieve the optimum yield. The schedule simply states that a fishery management plan must contain any measures.

> *"... considered necessary or desirable for the conservation or management of the fishery."*

Necessity and desirability only have meaning in the context of a given end, however, and so without some clear interpretation of what "optimum yield" means, it is impossible to determine what is necessary or desirable. While a draft fisheries policy was released in 1980, this policy is not based on the concept of optimum yield, and so it cannot be regarded as adequate for fisheries management planning.

It is my opinion, therefore, that more specific guidance is required before the optimum yield for the Pegasus Bay rig fishery can be adequately determined, and before management options can be discussed thoroughly and meaningfully. Consequently, it has been necessary to collate a list of factors which, I believe, must be considered if optimum yield is to be pursued as the goal of fisheries management planning. The list is not exhaustive, but, where possible, I believe that the optimum yield for this or any other fishery must be determined by giving due consideration to the importance of:

(i) harvesting the resource at a rate which is sustainable in the long term;

(ii) maintaining the stock at a size which ensures a high degree of security with respect to resource productivity (Crutchfield, 1973);

(iii) minimising catches of any species which are not utilised after harvest;

(iv) preventing or reducing over-capitalisation;

(v) encouraging fishermen to catch fish at the lowest possible cost (Crutchfield, 1965);

(vi) maintaining a satisfactory level of income for fishermen and fishery-related enterprises;

(vii) maintaining a reasonable return on fishermen's investments (Rothschild, 1971 *in* Alverson and Paulik, 1973);

(viii) encouraging the fishing industry to catch and process fish with techniques that ensure a high-quality product;

(ix) maintaining fishery-related employment opportunities (Anon, 1976 *in* Sinclair, 1978);

(x) the inter-relationships between different fisheries;

(xi) traditional fishing rights;

(xii) conserving and enhancing opportunities for recreational fishing;

(xiii) reducing user group conflicts;

(xiv) protecting and, where possible, improving the fisheries environment (Anon, 1980a);

(xv) minimising ecological disruptions in inter-species relationships; and

(xvi) promoting public awareness of the importance of maintaining healthy fish communities and ecosystems (Anon, 1976 *in* Sinclair, 1978).

It may be seen from this list that the optimum yield is not simply described by a numerical estimate of the physical yield. It must also be described in terms of how the yield is taken and, furthermore, who takes it.

Not even these factors describe the optimum yield by themselves however. The optimum yield must also be described in terms of the way that any desired combination of the above factors is achieved. If, for example, the same combination could be achieved in two ways, one of which was very costly to administer and one of which was not, then the total public benefit would not be as great as possible if the first management regime was adopted. Similarly, if one means of achieving the desired combination was very inequitable and one was not, then the more equitable management option would result in greater overall benefit for society. Thus, it is not possible to divorce the various means of achieving any desired combination of the above factors from the determination of the optimum yield. It is also necessary, therefore, to determine what factors influence the ability of each management option to attain the optimum yield.

Any management proposal for achieving the desired combination of those considerations listed in (i) - (xvii) above, must, in my opinion, be evaluated with regard to:

(i) the efficacy with which it would achieve the desired combination;

(ii) the distribution of costs and benefits which it would generate;

(iii) its robustness in the face of inevitable changes in fishing technology, costs, fish prices, and the availability of resources (Pearse, 1980);

(iv) the ease with which the proposal could be adapted should conditions change after its implementation;

(v) the costs of administering and enforcing the proposed management regime; and

(vi) the ease of administering and enforcing the proposed management regime.

Only when these factors have been considered along with those listed previously (and those not listed which are also relevant), will it be possible to determine what the optimum yield is.

The optimum yield from a fishery is the ideal combination of all relevant factors which results in the optimal utilisation of that resource for society. What is optimal for society is, however, a matter of opinion and no one opinion is more correct than another. Thus, the *real* societal optimum is uncertain. It is neither definable nor attainable. I wish to make the point very clearly, therefore, that the optimum yield described for this fishery is not *the* optimum yield. It cannot be. It is only my opinion on what the optimum yield is. Before describing the optimum yield, however, it is first necessary to examine the state of the Pegasus Bay rig fishery, and to assess the implications of non-management. These two factors also exert an important influence on the description of the optimum yield.

6.2 PRESENT STATE OF THE FISHERY AND THE IMPLICATIONS OF NON-MANAGEMENT

For management purposes, all rig on the east coast of the South Island can be treated as one stock. Since rig migrate extensively along the coast, the biological state of the Pegasus Bay fishery is determined by the combined activities of all fisheries along this coast. The biological state of the fishery can only be determined, therefore, by examining the condition of the stock as a whole.

Catch-effort analyses show that catch rates are declining rapidly in all three major rig fisheries along the east coast of the South Island. At Kaikoura, the catch rate has declined by 69% since its peak in the 1975-76 season. In the Pegasus Bay and Timaru-Oamaru areas, catch rates have declined by 72% and 65% respectively since their peaks in the 1977-78 season. The only accepted explanation for this is that the abundance of rig in the population is declining rapidly as a result of severe overfishing.

Tagging experiments also indicate that the rate of exploitation greatly exceeds the stock's productive capacity. Overall, the rate of exploitation is probably about 30% (Francis, 1983b). The sustainable exploitation rate is probably only about 5% (M. Francis, pers. comm.). The very high rate of female exploitation makes the situation more serious than even these figures would indicate, however. Rig probably have a direct stock-recruitment relationship, and so it is very likely that future recruitment is being severely affected at present exploitation rates. It has almost certainly been recruitment overfished in the past as well. There seems little doubt, therefore, that the Pegasus Bay rig fishery cannot be biologically viable for much longer under the prevailing harvesting regime.

On the whole, fishermen obtained very poor financial returns from the fishery in the 1982-83 season. A few fishermen did obtain minimum reasonable returns to their capital and entrepreneurship, but the majority obtained substantially less. Many did not even cover their costs. Even at the present rate of exploitation which greatly exceeds sustainable limits, none of the three groups of set net fishermen are earning sufficient net income to provide a reasonable return to their capital and entrepreneurship. The returns are also far less than those required to provide vessel owners with satisfactory returns to capital and entrepreneurship in the long term. Since the 1982-83 season was in line with the general catch rate trend, it is not considered to be an 'abnormal' year.

Indeed, it is likely to be better than those in the future if the current level of effort persists, as it is almost certain that the population will continue to decline at a rapid rate if effort continues to be applied at the current level.

The fishery is also in a serious economic position. The economic rent appears to be very close to zero, indicating that the fish are being harvested very inefficiently. The economic benefit of the fishery could be increased substantially through a reduction in both the amount of capital invested in the fishery and the amount of effort being applied. Since the current harvest is above the long-run equilibrium yield, it is very likely that the fishery will soon generate significant economic losses if the current harvesting regime continues.

Due to the probability of recruitment overfishing, both in the past and at present, it can be expected, I believe, that the rig stock will continue to decline at a rapid rate if fishing effort is not curbed. As catches decline, some fishermen which are less dependent on the fishery, will probably cease fishing. However, many will, I believe, continue to fish for the species. Rig is in good demand in the Canterbury area and so port prices generally increase with a fall in supply. Thus, prices will probably increase as catches dwindle. There is evidence of this already, as port prices were considerably higher in the 1983-84 season than in the 1982-83 season (C. Hill, W. Matthews, pers. comm.). Fishermen will be encouraged to keep fishing for the species, therefore, even if for shorter periods of time. Past trends indicate that they will use increased lengths of net to compensate for falling catches. Without some form of control, therefore, I do not believe that exploitation will fall to a sustainable level or that the stock will recover.

As catches fall, fishermen's profits will almost certainly decline. Returns from the fishery are already very poor, but it is likely that they will decrease even further as catch rates decline. This will undoubtedly force some fishermen from the fishery, and those fishermen which are not dependent on the fishery for an important part of their income, will probably restrict their fishing to times of peak catch. Both of these trends have been observed in recent seasons. Those fishermen who are dependent on the fishery for an important part of their income can be expected to face some financial difficulties. This may force them to increase their fishing effort or to exploit other species when rig catches are low. Some may choose to leave.

One perturbing trend which has developed in recent seasons is the practice of leaving nets set for extended periods before clearing them when catches are low. The result is an increased waste of fish and a reduction in the quality of the catch. This practice can be expected to become more prevalent if catches continue to decline.

While the Pegasus Bay rig fishery is left unmanaged, there will be very little chance of managing rig fisheries in other areas on the east coast of the South Island successfully. Rig move along the coast extensively and so, if other rig fisheries along the coast were managed but the Pegasus Bay fishery was not, then the benefits of catch or effort reductions in other areas would be at least partly dissipated through increased catches in Pegasus Bay. Not only is this inequitable, but it is also a waste of a lot of the time and money spent managing other rig fisheries. Similarly, reducing catch and effort in the Pegasus Bay rig fishery would not be biologically effective or cost-effective, unless management is implemented over the entire geographic range of the stock.

One factor which must always be considered when contemplating management is the cost of managing a fishery in relation to the benefits that management offers. This is always difficult to assess, but I believe that for very little cost the benefits from the rig fisheries could be substantially improved. Rig is a valuable species (the sixth most valuable for the domestic fleet in 1981) and the east coast ports of the South Island contribute a large part of the total landings. In 1982, the east coast ports between Golden Bay and Bluff yielded just less than 50% of the total New Zealand rig landings. Furthermore, the Pegasus Bay rig fishery, and possibly some others as well, is likely to generate significant economic losses if effort is not reduced. I would suggest, therefore, that the present utilisation of this resource is far less than optimal, that the potential benefits of management are large, and accordingly, that the stock should be managed.

6.3 OPTIMUM YIELD FOR THE PEGASUS BAY RIG FISHERY: A PERSONAL PERSPECTIVE

One very important characteristic of the optimum yield is that it is dynamic. Fishing costs, consumer demand, external employment opportunities, the size of fish stocks, and many other factors, are all continually changing.

Thus, what is optimal at one point in time, may not be optimal at another. Since it is not usually possible to predict how these factors will change, it is rarely possible to predict the long-term optimum yield.

No attempt is made to determine the long-term optimum yield for the Pegasus Bay fishery; first, because it is not known how a number of the above factors will change, and second, because there is a great deal of uncertainty over the biological and economic estimates provided in the following discussion. Estimated long-term biological yields are included in the discussion, however, as it is necessary to examine these yields as well as the short-term yields to present an accurate picture of the state of some fish stocks.

6.3.1 Biological, Economic and Social Aspects

A. Biological aspects

Although rig fishermen target fish for rig, they also catch a number of other species. It is necessary, therefore, to examine the state of these fish stocks, as well as the rig stock and to examine the impact of set netting on them when determining the optimum yield for the fishery.

(a) Present catches

Lyttelton[1] trawl and set net landings of the major species caught by the set net fleet are shown in Table 6.1. Figures shown are mean annual landings for 1981 and 1982.

Very little set netting occurs in Pegasus Bay between May and September. With the exception of flatfish, therefore, nearly all of the recorded set net landings of each species are taken between October and April. Most of this fish is probably taken by rig fishermen. It is not known, however, what proportion of each species' landings is taken while target fishing for rig.

Table 6.2 shows the catch composition of Group A, B and C operations for the October-April period in the 1982-83 season. Figures shown are mean catches per operation. Not all operations are included in the calculations as some fishermen have not sent statistical return forms in

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[1] Lyttelton landings include landings at all small ports around Pegasus Bay, e.g., Motunau and Sumner.

to the MAF. It is stressed that these are the recorded catches. Actual catches could differ considerably.

Table 6.1 Mean annual (1981-82) trawl and set net landings at Lyttelton of the major species caught by the set net fleet[a].

Species	Mean Annual Landings[b] (t)		
	Set net	Trawl	Total
Rig (*Mustelus lenticulatus*)	140.0	74.0	214.0
School shark (*Galeorhinus australis*)	58.8	27.0	85.8
Tarakihi (*Nemadactylus macropterus*)	23.1	122.7	145.8
Spiny dogfish (*Squalus acanthias*)	13.2	14.5	27.7
Warehou (mainly *Seriolella* spp.)[c]	12.2	94.7	106.9
Elephant fish (*Callorhynchus milii*)	11.3	47.1	58.4
Flounders (*Rhombosolea* spp.)	9.4	61.7	71.1
Hapuku (*Polyprion oxygeneios*)	4.7	26.1	30.8
Monkfish (*Kathetostoma giganteum*)	3.2	50.9	54.1
Dogfish unspecified	2.6	5.0	7.6
Shark unspecified	2.1	3.3	5.4
Soles (mainly *Peltorhamphus novaezeelandiae*)	1.9	165.0	166.9
Red gurnard (*Chelidonichthys kumu*)	1.3	73.7	75.0
Flats unspecified	0.7	110.4	111.1

[a] Source: MAF, unpubl. data.

[b] All figures are green weights.

[c] Excludes recorded landings of silver warehou (*Seriolella punctata*). Recorded "warehou" landings do, however, contain a mixture of several species, silver warehou included.

Table 6.2 Mean catch composition of Group A, B and C operations in October-April period of the 1982-83 season[a].

Species	Group[b]					
	A		B		C	
	Green weight (kg)	Percentage of total catch	Green weight (kg)	Percentage of total catch	Green weight (kg)	Percentage of total catch
Rig	7,810	59.3	10,070	49.0	870	50.2
School shark	2,240	17.0	5,910	28.7	100	5.9
Elephant fish	1,890	14.3	730	3.1	110	5.7
Spiny dogfish	540	4.1	1,360	6.6	60	3.5
Hapuku	130	1.0	160	1.1	0	0.0
Warehou	110	0.9	210	2.0	0	0.0
Flounders	20	0.2	250	2.2	30	2.7
Other	430	3.2	720	7.3	320	32.0
TOTAL	13,170	100.0	19,410	100.0	1,490	100.0

[a] Source: MAF, unpubl. data

[b] Sample sizes: Group A - 3; Group B - 6; Group C - 3.

(b) Total allowable catches

In the report recently prepared for the NAFMAC (Anon, 1983), the MAF provided estimates of the sustainable yields that the major commercial species could provide in each region throughout New Zealand. Since many stocks are under pressure at present, the MAF recommended interim yields for all species, as well as long-term yields. Interim yields are set lower than the long-term yields for most species to allow stocks to recover. Typical recovery periods are expected to be 5-10 years (Anon, 1983). Long-term yields should be indefinitely sustainable after the stocks have recovered.

The yield estimates provided are total allowable catches (TACs). It is not certain what level of exploitation these yields represent in relation to the maximum sustainable yield, as the report merely states that TACs have been set taking into account the best biological and economic data available at the time of writing. For biological purposes, however, TACs are usually set at approximately two-thirds of the maximum sustainable yield. This allows for error in the estimation of maximum sustainable yields. The TAC estimates provided in the report are probably in this vicinity.

It is important to recognise that the TAC estimates provided in the report are not precise. While they are the best currently available, some estimates are based on scant information. The Ministry's confidence in the estimates varies therefore. Of the species listed below, they are reasonably confident about the flounders and red gurnard estimates, less confident about the rig, tarakihi and soles estimates, and they are least confident about the school shark, blue warehou, hapuku and monkfish estimates. The figures are still very useful, however, as they at least provide an indication of what the sustainable yields from each region are likely to be. For the purposes of the report, Pegasus Bay is included in the Canterbury Bight region.

If the Canterbury Bight fish resources are to be equitably shared between fishermen, then it is necessary to rationalise the catch from each area within the region. This may not be of such major importance for the trawl fleet, as trawlers frequently fish in other areas. It is an important consideration for the set net fleet, however, as few set net vessels fish far from the home port. It is necessary, therefore, to devise some means of allocating the region's TACs between the different ports.

One reasonably equitable way of doing this is to allocate a TAC on the basis of each port's historical contribution to the regional catch of that species. By averaging the Lyttelton landings over some appropriate time period, therefore, and then changing this catch by the percentage indicated in the report, it is possible to derive suitable estimates of Pegasus Bay's "share" of the interim and long-term TACs for the Canterbury Bight. The percentage catch change to achieve the TACs is calculated in the report using 1981-82 average annual landings as an indicator of the present catches. Mean 1981-82 Lyttelton landings are also used to calculate Pegasus Bay's share of the Canterbury Bight TACs. Pegasus Bay's share of these TACs for the main species caught by the set net fleet, and for which regional TAC estimates are available, are shown in Table 6.3.

(c) Total allowable catches for Pegasus Bay set net fishermen

The next factor which is of critical importance in determining the optimum yield for the rig fishery is the relationship between the estimated rig TACs and the amount of rig taken by trawlers.

It is seen in Table 6.1 that the 1981-82 average annual trawl rig landings is approximately 74 t. This clearly exceeds the estimated interim TAC for Pegasus Bay and it is even higher than the long-term TAC. Under the present circumstances, therefore, the TACs are exceeded by the trawl harvest alone.

The important point about the trawl rig catch is that it is taken incidentally while target fishing for other species. Thus, the only way of decreasing the trawl rig catch would be to increase the mesh size to allow greater escapement, reduce trawling activity in the areas inhabited by rig, or reduce trawling activity in all of Pegasus Bay. I do not believe that it would be beneficial to implement any of these measures simply to ensure that the rig resource is harvested sustainably. The goal of management must be to optimise the returns from a region's fisheries as a whole, rather than optimising one at the expense of another. Trawl effort must, therefore, be regulated in accordance with the needs of all the region's fisheries and it cannot be decreased simply to ensure that rig are not overfished. Since trawl rig landings constituted only about 4% of the 1981-82 average annual Lyttelton trawl landings, it would not be reasonable to require trawlers to fish to avoid rig. Not only could this result in a large economic loss, but it is also unlikely to be effective in reducing

Table 6.3 Total allowable catches from Pegasus Bay of species caught by the set net fleet.

Species	Mean annual Lyttelton landings 1981-82 (t)	Required catch change[a] (%)		Total allowable catch (t)	
		Interim	Long-term	Interim	Long-term
Rig	214.0	-75	-69	53.5	66.3
School shark	85.8	-14	-14	73.8	73.8
Tarakihi	145.8	-40	+50	87.5	218.7
Blue warehou[b]	106.9	-43	-43	60.9	60.9
Flounders[c]	104.3	+20	+20	125.2	125.2
Hapuku	30.8	-20	-20	24.6	24.6
Monkfish	54.1	-17	-17	44.9	44.9
Soles[c]	244.8	+ 8	+ 8	264.4	264.4
Red gurnard	75.0	-20	+140	60.0	180.0

[a] Source: Anon, 1983.

[b] Assumed for these purposes, that all fish recorded as "warehou" are blue warehou (*Seriolella brama*).

[c] Assumed for these purposes, that "flats unspecified" is composed of the same ratio of flounders to soles, as is seen in "flounders" and "soles" recordings.

rig catches very much, as rig do not appear to inhabit a clearly defined area. They move about extensively.

In the report prepared for the NAFMAC, the NZFIB provided estimates of the number of full-time vessels less than 30 m long, that each region can support, given the estimated TACs. These estimates indicate that there is a need for a substantial reduction in the number of full-time vessels working in the Canterbury Bight region. If trawl effort reductions do occur as recommended, then the rig catch could decrease. With the uncertainty surrounding both the scale of trawl effort reduction and the effect that this will have on rig catches, it is impossible to predict how much trawl rig catches will decrease by. I would suggest, however, that it is very unlikely that it will even be reduced this far. It seems probable, therefore, that the rig TAC will continue to be taken by trawlers alone. Thus, the amount of rig available to set netters must, on biological grounds, be regarded as zero.

The most important by-catch species taken by rig fishermen is school shark. This is taken in considerable quantities by set net fishermen as indicated in Tables 6.1 and 6.2. Trawlers also take significant quantities of this species as a by-catch, but they do not harvest the entire interim or long-term TACs. Thus, unlike rig, it appears that there is scope for exploitation of this species by set net fishermen. Tables 6.1 and 6.3 suggest that set net fishermen could harvest approximately 45-50 t of school shark without overfishing the species.

Elephant fish are another major by-catch species in the fishery, particularly for Group A fishermen. No TAC estimates are available for this species and so it is impossible to derive quantitative estimates of the amount of elephant fish available for harvest by trawl and set net fishermen. The stock does not yet appear to have fully recovered from the collapse which occurred in the mid 1970s and so it is very unlikely that the interim TAC would be higher than present catches (A. Coakley, pers. comm.).

Spiny dogfish are also a significant by-catch species in the fishery; far more significant than recorded landings would indicate, as much of the catch is discarded at sea. No TAC estimates are available for this species either. Spiny dogfish are abundant off the Canterbury coast, however, and are as yet only exploited lightly. It is probably possible to increase catches considerably without overfishing the stock.

All other by-catch species caught by rig fishermen appear to form only a very minor part of the total catch (see later for explanations of tarakihi and warehou catches). Catches of most of these species also need to be reduced in the short-term; flounders and soles are the two exceptions. In the long-term, flounders, soles, tarakihi and red gurnard catches may be increased, some substantially, but other species require permanent catch reductions.

Although the TAC estimates used in this study are based on the best information which is available at present, there is considerable uncertainty about the accuracy of the estimates. Under these circumstances it would seem prudent to be conservative when deciding upon appropriate TACs for the fishery.

B. Economic aspects

(a) Rig

Several important points have arisen from the preceding sections. First, trawlers alone will probably harvest both the interim and long-term rig TACs. Second, they will take this fish as a by-catch, which is probably only avoidable at considerable economic cost. Third, the fishery can be expected to generate significant economic losses in the future if it continues in its present form.

One important conclusion to emerge from these points is that since trawlers will take rig as a by-catch, they will not only harvest the entire rig TAC, but they will harvest it at the lowest possible cost. No resources will be specifically used to catch the rig TAC, but it will probably still be taken. Under the present circumstances, therefore, it would be impossible to harvest the rig TAC with any greater economic efficiency. In view of these factors, I would suggest that unless the trawlers take considerably less than the rig TAC, which is unlikely, the *bioeconomic* optimum rig harvest will be what the trawlers catch. Even if they do catch significantly less than the TAC, their catch could still represent the bioeconomic rig catch, as it would enable the rig stock to recover more quickly.

(b) Other species

While the set net rig TACs must, on biological and economic grounds only, be regarded as zero, it is seen from Tables 6.1 and 6.3 that there is scope for set net exploitation of some species without overfishing the stocks. It is necessary to determine how many fishing operations these resources could support and provide reasonable returns to capital and entrepreneurship to. Since Group C vessels are assumed to have been eliminated from the fishery, estimates are only provided for Groups A and B.

The following calculations are complicated by two factors. The first is that it is not known how target fishing for species other than rig would alter the fishing costs data used in earlier analyses. It is necessary, therefore, to assume that the fishing costs presented in the earlier analyses will not alter significantly with a change in the target species.

The second factor is that it is not known what the catch composition would be if fishermen started target fishing for some species. For this reason, each species is treated separately. The estimates provided are estimates of the number of vessels that each species' TAC could support, if vessels fished for that species for the full 14 week period.

The number of fishing operations which could be supported will also vary depending on the ownership arrangements of the vessels involved. Both the number of sole owner-operated vessels and the number of partnership owner-operated vessels that the resources could support are estimated, therefore. This requires some adjustments to the costs data seen in Tables 5.4 and 5.5 and to the income equations seen in section 5.3.3, as some operations which provided data had wage costs while others did not. If it is assumed that the average wage costs of all sole owner-operated vessels would be equal to 15% of the gross earnings, then the income equations for sole owner-operated vessels are:

$$Y_A = 0.51\ X_A - 4980 \qquad (6.1)$$

$$Y_B = 0.36\ X_B - 9270 \qquad (6.2)$$

To determine the partnership owner-operated vessel income equations, it is necessary to deduct wage costs altogether. Thus, the income equations for partnership owner-operated vessels are:

$$Y_A = 0.65\ X_A - 4980 \qquad (6.3)$$

$$Y_B = 0.51\ X_A - 9270 \qquad (6.4)$$

Returns to entrepreneurship and capital are again estimated at $4040 per owner and 10% respectively, as in section 5.3.5. Once again, only 14/52 of Group A's total annual return to capital is assigned to the set net season.

The revenue which the average Group A and Group B operation would require to obtain a minimum reasonable return to capital and entrepreneurship, based on these data and the above income equations, is shown in Table 6.4.

Table 6.4 Gross earnings required to provide Group A and Group B operations with a minimum 'reasonable' income.

Group	Return to capital ($)	Return to entrepr. ($)	Minimum net income ($)	Minimum required revenue ($)
A				
(a) Sole owner-operated	640	4040	4680	18,940
(b) Partnership owner-operated	640	8080	8720	21,080
B				
(a) Sole owner-operated	1870	4040	5910	42,170
(b) Partnership owner-operated	1870	8080	9950	37,690

Using this information it is now possible to obtain the required estimates of the number of vessels that the available resources could support.

It was noted in the previous section that once the trawl by-catch of school shark is deducted from the school shark TAC, there is still approximately 45-50 t of fish remaining for set net fishermen. Large and small school shark trunks usually sold for about \$1.90/kg and \$2.60/kg respectively in the 1982-83 season (G. Morris, pers. comm.), and so it is probably of a high enough value to support some fishermen. The main problem with this species is that it frequently shows strong patterns of seasonal abundance. It may not be sufficiently abundant, therefore, to support fishermen over an extended period. Commercial catch data show that set net school shark catches remained relatively constant over the November-February period in 1981 and 1982, however, and so it may be abundant enough to support some operations for at least 1-2 months each season.

Fishermen who have target fished for school shark in the past have found that school shark usually comprise 80-95% of the total catch (W. Matthews, G. Morris, pers. comm.). Approximately 80-90% of the school shark catch is composed of small fish (G. Morris, pers. comm.). Hapuku is the major by-catch species with all other species forming only a very minor part of the total catch (W. Matthews, G. Morris, pers. comm.). Hapuku usually sold for about \$2.20/kg (headed and gutted) in the 1982-83 season.

If it is assumed that

(i) school shark would compose 85% of the total catch, with 85% of the fish being small;

(ii) large school shark trunks fetched an average of \$1.90/kg and small school shark trunks fetched an average of \$2.50/kg in the 1982-83 season; and

(iii) that the remainder of the catch would be worth approximately \$2.00/kg headed and gutted,

then the port price and catch data can be combined to obtain an average port price for the catch as shown in Table 6.5.

Using this data and the revenue data shown in Table 6.4, it is now possible to estimate the amount of fish that each operation must catch to obtain reasonable returns to capital and entrepreneurship, and therefore, the number of operations that the school shark TAC could support. These data are shown in Table 6.6. For the purposes of the calculations, the school shark TAC for set net fishermen is estimated to be 47 t.

Spiny dogfish is another species which has the biological potential to support some fishermen. There is local evidence of increased interest

Table 6.5 Estimated catch composition and average port price of catches taken while target fishing for school shark.

Species	Percentage of total catch	Average port price[a] ($/kg)	Weighted port price ($/kg)
School shark			
(a) Small	72.3	1.25	0.904
(b) Large	12.7	0.95	0.121
Other	15.0	1.43	0.215
TOTAL	100.0		1.240

[a] Estimated average for the 1982-83 season. All port prices are converted to green weight equivalents, using unpublished MAF conversion figures.

in the species, and one processing company in Timaru has begun exporting it. During the 1982-83 season, fishermen usually obtained approximately 80¢/kg for dogfish trunks. This makes it of low value compared to other species, but the price could increase if rig catches continue to decline, or if target rig fishing ceased. At present, however, there is still a limited demand for the species and if large quantities were landed it is doubtful whether all of the fish could be sold without a significant decrease in the price or indeed even sold at all. If set net landings were able to double from 13 t to 26 t without adversely affecting the port price, then the species could support one Group A operation for a full season, or the equivalent thereof, or one Group B operation for half of one season, or the equivalent thereof (see Table 6.6). Thus, at present, it does not appear that the species can provide the basis for a significant fishery.

Although none of the rig fishermen target fished for tarakihi in the 1982-83 season[1], the MAF records show that approximately 46 t of tarakihi was landed by set net fishermen in the 1981-82 season. Some set

[1] The mean green weight of tarakihi landed by Group A and Group B operations in the 1982-83 season was 15 kg and 18 kg respectively.

net target fishing for tarakihi has taken place in Pegasus Bay in the past but it is not thought to have occurred on the scale required to produce landings of this magnitude (A. Coakley, G. Morris, pers. comm.). There is a possibility, therefore, that the 1981-82 season's set net tarakihi landings are the result of a coding error or, alternatively, that some vessels have caught tarakihi in another area (e.g., Kaikoura) and consistently landed them at Lyttelton. However, since the catches may have actually been taken from Pegasus Bay, and since all other estimates have been based on the 1981-82 annual average, the number of fishermen that this species' TAC could support is estimated.

Table 6.3 shows that although the tarakihi catch can increase substantially in the long term, it needs to be reduced from about 150 t to about 90 t in the short term, to allow the stock to recover. Since tarakihi is a target species of the local trawl fleet, the trawl fleet could avoid catching the species. Thus, the set net TAC is calculated by reducing both trawl and set net catches by the same percentage (40%). This results in a tarakihi TAC for set net fishermen of approximately 14 t in the short term.

The major problem encountered when trying to estimate the number of fishermen that the set net TAC for this species could support is that there is insufficient information to determine what the catch composition would be. Mr G. Morris, a local commercial set net fisherman who has target fished for tarakihi in Pegasus Bay, found that the catch composition varied widely over very short intervals. On some occasions, the catch was almost exclusively composed of school shark. Significant quantities of blue warehou were also caught on occasions. Mr Morris was, however, fishing with 178 mm and 228 mm mesh nets. At Kaikoura, tarakihi are usually fished with 117-139 mm mesh nets (Irwin, 1982). These sized nets would produce a different catch composition again. Very little school shark would probably be caught in these nets. Species such as blue warehou and red gurnard would probably be more important.

With this variation and uncertainty, it is considered impracticable to estimate what the catch composition would be. The estimates shown in Table 6.7 are based on the tarakihi set net TAC only, therefore; no account is taken of the earnings which by-catch species would provide. This will result in an underestimation of the number of operations that this TAC could support. Estimates are based on the average port price paid to fishermen for tarakihi in the 1982-83 season; \$1.30/kg green weight (G. Morris, pers. comm.).

Warehou is another species which formed only a very minor part of rig fishermen's catches in the 1982-83 season, but which was taken in much greater quantities (approximately 20 t) by set net fishermen in the 1981-82 season. Catches of this species in the 1981-82 season, correlate very closely with the tarakihi catches and so it seems likely that the fish were taken as a by-catch while target fishing for tarakihi. Present blue warehou catches must also be reduced considerably (43%) in both the short and long term, but even the current set net harvest is of virtually insignificant importance as the species was only worth about 90¢/kg green weight to fishermen in the 1982-83 season. It will probably be taken as a by-catch at present, therefore, and it is not likely that the species will supplement fishermen's income to any great extent.

Of the species examined in this study, flounders and soles offer the greatest potential (next to spiny dogfish) for catch increases in the short term. It is estimated that catches of these two groups of species could increase by 20% and 8% respectively, without overfishing the stocks (Anon, 1983).

Although fishermen obtain good prices for flounders and soles (approximately \$2.00/kg green weight and \$2.30/kg green weight respectively in the 1982-83 season), even the above increases provide only very small set net TACs for these species if catches are increased in proportion to the average 1981-82 annual catches; the set net flounders TAC would be only about 11 t, and the set net soles TAC would be only about 2 t. Most of the set net catch of these two groups of species has traditionally been taken by flounder and sole fishermen working inside Lyttelton Harbour. Some of these fishermen have probably been excluded from commercial fishing as a result of the first national effort reduction step. No attempt is made to estimate the number of operations that these TACs could support; first, because the number of fishermen which have been excluded is unknown, and second, because fishing costs are expected to change considerably if fishermen did begin to target fish for this species (e.g., fuel costs would probably decrease substantially).

The number of operations that the TACs examined above could support are summarised in Table 6.6. It must be stressed that there is considerable

Table 6.6 Number of operations that school shark and tarakihi total allowable catches and spiny dogfish resource could support for a full season.

Group	Minimum required green weight per operation[a] (t)			Number of operations[b]			
	School shark[c]	Tarakihi[d]	Spiny dogfish[e]	School shark	Tarakihi[d]	Spiny dogfish[e]	Total
A							
(a) Sole owner-operated	13.0	13.5	23.7	3.6	1.0	1.1	5.7
(b) Partnership owner-operated	14.5	16.2	26.4	3.2	0.9	1.0	5.1
B							
(a) Sole owner-operated	28.9	32.4	52.7	1.6	0.4	0.5	2.5
(b) Partnership owner-operated	25.8	29.0	47.1	1.8	0.5	0.6	2.9

[a] Catches required to provide operations with a minimum reasonable return to capital and entrepreneurship.

[b] These are full season 'equivalents'.

[c] These are school catches only. Total required catches from the top to the bottom of the table are 15.3 t, 17.0 t, 34.0 t and 30.4 t.

[d] Calculations assume that there is no by-catch. The number of operations that this TAC could support will be underestimated therefore.

[e] Assumed for these calculations that the set net catch of spiny dogfish could double without adversely affecting the port price.

uncertainty associated with these estimates. Since very little target fishing has occurred for these species, neither the catch compositions nor the availability of these species can be predicted with accuracy. Port price and demand trends are also uncertain. All of these factors will have a large impact on the number of operations that the available TACs can support. Much of this uncertainty would be removed if fishermen began to target fish for the species which the estimates in Table 6.6 are based on. Thus, the number of vessels which the TACs can support could be estimated with much greater accuracy after even one fishing season. For the present, however, it is essential to at least obtain some indication of how many fishermen the resources might be able to support in the short term. This is the only purpose of the above calculations.

C. Other aspects

Very little information is available on recreational fishing and traditional fishing rights in the Pegasus Bay area. The major species caught by rig fishermen are not thought to be taken in any significant quantities by recreationalists, however, and they are not thought to be of great traditional significance to any particular sector of the community. If it became evident during the fisheries management planning process that either of these interests was important, then the above estimates would need to be revised. For the present, however, this does not seem to be necessary.

Of all the factors which could influence the estimates provided above, the two most significant are, I believe, fishermen's dependence on the fishery and their ability to find alternative employment. The degree to which these factors should modify the yields and level of effort in a fishery is very much a matter of opinion. My own opinion, however, is that if there is a need to reduce fishing effort, either to reduce pressure on a stock or to provide fishermen with reasonable incomes, then these reductions should occur, unless fishermen would suffer undue financial hardship as a result of being excluded from the fishery.

Group A operations are owned by full-time fishermen. It appears from the survey that these fishermen earn between 25-40% of their annual gross earnings from the set net fishery. Since fishing costs are significantly less when set netting than when trawling (mainly because of the lower fuel costs), it is likely that the set net season provides these fishermen with an important part of their income. If excluded from the fishery, it is expected that they would return to the trawl fleet for this period.

Group B fishermen do not fish full-time. They all have alternative occupations during the off-season and many are self-employed. In view of the very low returns that most Group B operations obtained during the 1982-83 season, it seems very likely that most Group B owners could have earned greater profits from their other occupations during this period than they did from the fishery. However, the fishery may well provide some owners with an important part of their income.

If a Group B fisherman was excluded from fishing, he would still have to meet some costs, e.g., interest on any loans. The real costs would not be as high as the fixed costs figured in Table 5.5 would indicate. Most of Group B operations' fixed costs are composed of depreciation costs and, if the vessel and nets were idle, the real decline in asset value would be considerably less than than estimated in the table. If excluded from fishing, it is extremely unlikely that a fisherman would be left unemployed during the fishing season.

One group of fishermen about which very little has been said so far, is the full-time set net fishermen. These fishermen were placed in Group C in earlier discussions as there are only two known full-time set net fishermen and neither of these fishermen was target fishing for rig during the 1982-83 season. One of these fishermen was target fishing for rig during the 1983-84 season. Since the scope of this study has now broadened to include all set net species, it is important to consider these fishermen.

These two fishermen are, I would suggest, more dependent on the set net fishery during the summer months than any other group. Neither has alternative employment and neither is geared to join another fishery if excluded from the set net fishery. The hardship which would result if these fishermen were excluded from the fishery would depend on their ability to find another job. The consequences of excluding them from the fishery are, however, harsher than for either the other two groups, as they are the only group of fishermen which would be left unemployed.

Another factor which must be examined is the effect that excluding fishermen would have on other fisheries. This is also a very important determinant of how the yields and fishing effort should be modified.

If Group A operations were excluded from the fishery, they are likely to return to the trawl fleet. I see no reason why they should be prevented from doing so. Since the trawl fisheries in the Canterbury Bight region are also under stress, it would seem to be unwise to increase effort in these fisheries even further, unless there were very good reasons for this. Removing the Group A fishermen from the set net fishery, therefore, would simply result in a shift of fishing effort from one stressed fishery to another. While it may solve some of the problems in the set net fishery, it would not alleviate the problems of the region as a whole; it would only change them.

If the full-time set net fishermen or Group B fishermen were excluded from the set net fishery, it is very unlikely that they would be able to obtain a permit for another fishing method. Assuming that these fishermen would not be able to join set net fisheries in other areas, then the removal of either of these groups would result in an overall decrease in fishing effort in the region.

D. Summary

It appears from historical catch data that the trawl rig catch alone will exceed the estimated interim and long-term sustainable rig TACs. This catch is unavoidable, as it is a by-catch. Because trawlers will take the TAC as a by-catch, they will harvest the TAC at the lowest possible cost.

It seems likely that other species can be exploited by the set net fleet without being overfished. The total quantity of fish which can be harvested without overexploiting the species is small, however. Of the significant by-catch species, only spiny dogfish appear to be capable of accommodating increased catches. While school shark catches must be reduced, there is scope for exploitation of this species by set net fishermen without overfishing the stock. Some increases in landings of the minor by-catch species are possible in both the short and long term. Several of these latter species are major trawl species and not all of the increased allowable catch can be expected to be available to set net fishermen.

If the assumptions used in the calculation of set net TACs are accepted, then it appears from Table 6.6 that there is a very limited potential for these TACs to support commercial fishermen. They could perhaps support five or six Group A operations, or two or three Group B operations. School shark seem to offer the greatest potential at present, but in practice they may not be sufficiently abundant to support fishermen all season. Nevertheless, a small number of fishermen could probably earn a reasonable living, if they fished for other species (e.g., tarakihi) when school shark were not abundant. Some species not examined (e.g., butterfish and moki, *Latridopsis ciliaris*) could also support fishermen for short intervals during these times. As stocks recover and marketing barriers are overcome, the fish resources in the area could probably support a greater number of set net fishermen than is possible at present.

Very few of the fishermen would be left unemployed if excluded from the fishery. Most are not expected to suffer financial hardship if excluded either. I believe that this is substantiated by the fact that a number of fishermen who fished full-time or virtually full-time during the 1982-83 season, fished very little or voluntarily ceased fishing altogether in the 1983-84 season. If the set net season provided these fishermen with a vital part of their income, then this would not have occurred. In general, however, the full-time set net fishermen are probably more dependent on the fishery than either of the other two groups of fishermen, and Group A operators are probably more dependent on the fishery than Group B operators.

6.3.2 Managing for Optimum Yield

A large number of regulations may be used to achieve management objectives. These regulations may be classified into two general groups:

(a) Regulations affecting the composition of the catch

- (i) mesh size restrictions
- (ii) closed seasons and areas
- (iii) size, sex and condition limits.

(b) Regulations affecting the size of the catch

- (i) catch quotas
  - total
  - individual

(ii) effort control
- restrictions on the type and deployment of gear
- restrictions on the number of vessels.

Any one of these regulations may be used singly, or it may be used in combination with other regulations.

A. First step towards attaining the optimum yield

The existing biological problem in the Pegasus Bay rig fishery is that the harvests of most species are too large. The cause of this problem is too much fishing effort. Implementing regulations to affect the composition of the catch will not overcome the problem therefore, because these regulations do not address the cause of the problem. Thus, as a starting point, it is necessary to examine means of regulating the size of the catch.

(a) Catch quotas

(i) Total quotas. Total quotas are frequently used by regulatory agencies as a conservation measure. They are usually biologically effective as once a quota is reached fishermen are required to target fish for other species or cease fishing altogether.

To reduce catches to sustainable levels in the Pegasus Bay fishery, it would be necessary to set quotas at or near to the estimated TACs. Since the total of all set net TACs is much smaller than could possibly support the existing set net fleet, total quotas are likely to generate severe competition. Some fishermen may withdraw from the fishery, but those left would be encouraged to increase their fishing effort, to obtain the largest possible share of the quotas.

Competition for total quotas would have a number of adverse consequences. First, it would lead to a decline in the economic efficiency of the fishery. This would result from an increase in the costs of catching the fish (through excessive deployment of fishing effort) and from an increase in the time that vessels and nets are idle. Since many vessels are already idle for all but three or four months each year, it would not seem to be wise to reduce their use further if this could be avoided. Second, it would reduce fishermen's incomes. This again results from an increase in fishing costs and a decrease in the time taken to harvest the quotas. Third, it would create decreased and less stable employment in the fishery.

This also arises from a decrease in the time taken to harvest the quotas and it causes additional adverse consequences for those who are dependent on the fishery. Finally, increased competition could be expected to generate increased conflict over gear use, both between set net fishermen and between set net and trawl fishermen.

To be successful in achieving biological sustainability, it would probably be necessary to impose a quota on all species which are capable of being taken in significant quantities by set net fishermen. Imposing a total quota of zero on rig for instance, may be effective in achieving the required catch reductions for rig, but without setting a quota all other species as well, the effect would simply be to transfer effort to other stocks. For most species, the TACs are so small that it would be impracticable to have a quota. The costs of enforcement relative to the benefits of setting quotas would probably not make such a scheme cost-effective. Imposing a total quota on certain species without dividing the quota up between different fishing methods would promote conflict between trawl and set net fishermen. There is already considerable conflict between these two groups of fishermen and aggravating the problem is to be avoided if possible.

By themselves therefore, total quotas are not considered to be a satisfactory means of regulating the size of the yields in this fishery. They would cause a deterioration in economic and financial conditions, and because they are unlikely to be enforceable, they would probably not establish a sustainable harvesting regime. It is expected that total quotas would also promote conflict over gear use.

(ii) Individual quotas. An alternative form of quota control is individual quotas. Individual quotas avoid a number of the adverse consequences of total quotas and they appear to offer substantial potential for greatly improving the utilisation of fisheries resources.

This type of regulation is not considered in detail here, for the simple reason that I do not believe that individual quotas are enforceable at present. Wholesaling and retailing companies are not required to send details of their purchases from individual fishermen to any regulatory body and so it would be impossible to determine when a fisherman had reached his quota of either one species or all species. Relying on commercial return forms would be entirely inadequate. There could be considerable delay between the time a quota was reached and the time this was detected. Furthermore, fishermen would probably under-report their catches, particularly when they neared their allocation of fish. The result would be that the system would not be effective in achieving biologically sustainable harvests and the quality of catch and effort statistics would decline. Unless any management system is enforceable, then there is very little chance that it will be successful. Until such time as individual quotas are enforceable, therefore, there is very little point in implementing them.

(b) Effort controls

(i) Restrictions on the type and deployment of gear. Regulations of this type include measures such as mesh size restrictions, closed seasons and closed areas. These regulations can also be an effective means of controlling the size of the catch.

Closed areas are considered to be a poor means of reducing set net catches to sustainable levels in the Pegasus Bay fishery. Most set net species do not appear to inhabit a clearly defined area within the bay and so it would be necessary to close large areas to achieve significant catch reductions. Concentrating fishing effort into small areas would reduce the amount of fish available to each unit of effort. Thus, it would take more effort to catch the same amount of fish. Closed areas would reduce fishermen's incomes and economic efficiency therefore, as they would raise fishing costs. Concentrating fishing effort into small areas would also create increased conflict over gear use.

Closed seasons have a number of consequences which are similar to those associated with total quotas and closed areas. They too would have a number of disadvantages.

One major problem which would be encountered if closed seasons were used as a means of regulating the size of the catch, is that it would be difficult to determine how long a season should remain open. Historical catches would not be a reliable indicator of the time it would take to harvest any one of the TACs as the very existence of a closed season would change the fishermen's behaviour. Since the TACs are very small, it would be necessary to monitor landings closely, to determine when a season should be closed. The small size of most TACs would also make the regulations complex, as seasons would inevitably be very short. All of these factors would make both administration and enforcement difficult and costly. In a fishery as small as the Pegasus Bay rig fishery, I do not believe that this can be justified.

If fishermen knew that they had a limited time available to catch a species, then they would behave in much the same way as if a total quota existed. Fishing effort would be excessively deployed during the season to catch the largest possible quantity of fish. The inevitable result of these measures, therefore, would be a decline in both individual incomes and economic efficiency. If closed seasons were as short as is expected, then the consequences of mechanical breakdown or temporary illness could also be serious for those who are dependent on the fishery for an important part of their income. Once again, gear use conflicts would be accentuated if these regulations were implemented.

Other regulations in this group affect the type of gear which can be used. Mesh size restrictions and banning monofilament nylon mesh are two such measures which could be employed in the Pegasus Bay fishery. These regulations are not considered in detail here. They could only restrict catches to sustainable levels by reducing the catching efficiency of the gear substantially and thus they would have very similar consequences to all other regulations in this group.

Overall, it is not considered possible to attain the optimum yield with these regulations alone. All of the regulations would reduce fishermen's incomes and economic efficiency and some would promote increased conflict over gear use. Administration and enforcement would also be difficult and costly if some of these measures were implemented.

(ii) Limiting the number of vessels. Two points which have emerged so far are of fundamental importance for determining the optimum yield. First, it will be impossible to harvest the resources sustainably and provide fishermen with reasonable incomes without reducing the number of vessels in the fishery. The TACs are simply too small to support the existing fleet. Second, if the number of vessels is not reduced, any attempts to achieve sustainability will promote severe competition. While competition is severe, fishermen's incomes and economic efficiency will continue to decline and conflict between gear users will increase. Administration and enforcement will also become more difficult and more costly.

If the number of vessels is not reduced, the best that can be achieved is biological sustainability. If the fleet is reduced, however, it is possible to achieve sustainability, provide fishermen with reasonable incomes *and* promote economic efficiency. Reducing the size of the fleet would also decrease the incentive to expand fishing effort as each fisherman would have fewer competitors. This would make administration and enforcement less complex and less costly.

Since many fishermen have alternative employment, I do not believe that most fishermen would suffer hardship if excluded from the fishery. Excluding some fishermen would, in my opinion, create far less hardship than if total quotas or the above effort controls were implemented without restricting access to the fishery. Thus, limiting the number of vessels in the fishery is considered to be an essential prerequisite to attaining the optimum yield.

The main objection to limited entry programmes is that, by definition, they restrict some individuals' freedom to fish and they confer certain privileges to those who are entitled to fish. The manner in which entry is restricted is very important therefore.

Entry to a fishery may be limited in one of three ways: first, by taxing fishing effort, the catch or the vessel owner; second, by issuing licences or permits to a set number of vessels or vessel owners, and third, by allocating individual quotas.

Taxes are not a preferred option for regulating access to the Pegasus Bay fishery. Initially, it would be difficult to determine how high any one of the taxes should be set so that the 'right' number of vessels was left in the fishery. Furthermore, even in the short-term, it could be necessary to adjust the tax to keep the right number of vessels in the fishery. As a result, administration would probably be difficult and costly. Taxes which were high enough to force fishermen out of the fishery, would also reduce the incomes of the remaining fishermen. Returns are already poor and any further reductions are regarded as detrimental in the short-term. Any measure which reduced fishermen's profits would also generate the need for further regulations, as it would encourage fishermen to increase their fishing effort. Individual quotas are also not favoured for the reasons mentioned previously.

The most appropriate means of limiting entry in the Pegasus Bay rig fishery is, in my opinion, to issue a restricted number of fishing permits. If access was restricted by simply denying some fishermen the ability to register their vessels and obtain a fishing permit when next due (in October, before the season begins), then additional administrative costs would be minimal. Costs are only likely to increase if appeals were lodged. This method of limiting entry was used recently to exclude a number of part-time fishermen from the inshore fishing industry (including some from the Pegasus Bay rig fishery) and it could be readily employed to exclude further fishermen from the fishery. Enforcement would not become any more difficult or costly than at present and the fishermen which did obtain permits would not face any extra costs.

There are a number of details relating to limited entry systems (e.g., whether to make permits transferable, whether to issue permits to vessels or fishermen) which are not pursued here. The reason for this is that any changes in the present system of permit issue and vessel registration are more likely to be matters of national policy. The important task at present is to determine which and how many fishermen should be entitled to remain in the fishery.

The First Schedule of the Fisheries Act (1983) states that:

"*Any fishery management plan may....*

(d) Establish a system for limiting access to the fishery to persons who can satisfy the Director-General of their eligibility having regard to the following criteria or such of these as may be specified in the plan:

(i) Present participation in the fishery.

(ii) Historical fishing patterns and dependence on the fishery.

(iii) The economics of the fishery.

(iv) The capability of fishing vessels being used, or intended to be used in the fishery, to operate in other fisheries.

(v) Any other relevant considerations."

The "other relevant considerations" which are examined in this study are economic efficiency, the effect on employment, the nature of the participants' fishing practices, and the effect on other fisheries.

The weighting which is assigned to each of the above considerations is a matter of opinion. In my opinion, however, dependence on the fishery is the most important consideration. For this reason, I believe that it would be desirable to enable full-time set net fishermen to remain in the fishery. It is unlikely that these fishermen would be able to obtain a permit to fish in another fishery and, as a result, they would be left unemployed if removed from the fishery. They are the only group of fishermen who would be unemployed if excluded from the fishery. Since there appear to be enough fish to support all of these fishermen, I believe that they should be given priority to remain in the fishery.

Of the remaining fishermen, I believe that it would be preferable to enable Group A fishermen to remain in the fishery rather than Group B fishermen. There are a number of reasons for this. First, at least some of the Group A fishermen seem to rely on the fishery for an important part of their income. Some Group B fishermen may also rely on the fishery, but this is considered less likely. Removing Group A operators from the fishery would improve the income of Group B operators, but decrease the income of Group A operators and all other trawl fishermen. In view of the fact that Group B operators have alternative employment, I do not believe that this is acceptable. The first obligation as I see it, must be to protect the livelihood of full-time commercial fishermen.

The second reason for favouring the exclusion of Group B operators before Group A operators is that fishing pressure would increase in other fisheries if Group A operators were excluded from the set net fishery. Some effort would be removed from the set net fishery if Group A fishermen were denied set net permits, but this effort would simply be transferred to the trawl fisheries which are also under stress. The overall level of effort in the region would probably not change very much, therefore, if Group A operators were removed from the fishery.

The third reason is that Group A fishermen catch their fish with much greater efficiency. They caught considerably less fish than Group B operators during the 1982-83 season, but still earned a much higher net income. It is possible, therefore, to attain both a greater economic efficiency and a higher level of employment in the fishery if Group A fishermen are allowed into the fishery in preference to Group B fishermen.

The fourth reason for giving preferential entry to Group A fishermen is that their fishing practices are less wasteful, biologically. Most Group A fishermen remain at sea with their nets for two or three days and bring the nets back to port at the end of a fishing trip. This reduces the risk of net loss. If nets are lost in shallow waters such as Pegasus Bay, they will roll up after a period of time through the combined actions of the tide, weather and captured fish. This reduces the likelihood that fish will be caught, but some fish and crustaceans continue to be caught even after the nets have rolled up (Anon, undated). If lost in deep water, nets are unlikely to roll up and may continue to fish or drive fish away from an area for a long period of time. The result of losing nets, therefore, can be a large waste of fish, both before and after they roll up.

Even when nets are not lost, a large amount of fish can be wasted if fishermen leave their nets set in the bay as Group B fishermen and one or two Group A fishermen do. These fishermen are frequently unable to clear their nets for some time during periods of rough weather, and during periods of low catch it is common practice for these fishermen to clear their nets only every two or three days. This results in a large waste of fish as by the time the nets are cleared a significant part of the catch has frequently been eaten by predators, spoiled, or reduced to a low quality. I have personally been on vessels where more fish has been discarded because it is rotten, than has been landed. This is deplorable at the best of times, but when a stock is already stressed it is inexcusable. High quality and reduced wastage must be encouraged in the interests of both the fishing industry and the consumer, and so I believe that there is good reason to promote these goals when given the opportunity.

During the debate over effort reduction in the inshore fisheries, it has frequently been stated that removing part-time fishermen from the industry will do very little to reduce fishing effort in the inshore fisheries. While this may be true nationally, it is not necessarily true locally. Group B operations landed far more fish than Group A operations during the 1982-83 season, both in total and per operation. Removing part-time fishermen from this fishery, therefore, would result in a large reduction in fishing effort and importantly, a larger reduction per operation than if full-time fishermen were removed. Thus, removing Group B fishermen would also be more effective in reducing fishing effort than if Group A operations were excluded.

Since the moratorium has been in place, only those individuals who held current permits on 18 March 1982 have been able to fish commercially[1]. The moratorium has not prevented part-time fishermen from becoming full-time fishermen, however. In my opinion, therefore, excluding Group B fishermen is not unduly discriminatory. The first responsibility as I see it is to protect the livelihood of full-time commercial fishermen. Group B fishermen are not in this category because they have chosen not to be. It is worth dwelling on the fact that since a moratorium is in place, those in the fishery at present are already enjoying certain privileges. Excluding Group B fishermen is no more discriminatory than the moratorium is against other individuals who wish to become fishermen.

In view of the need to limit the number of vessels in the fishery, therefore, I believe that there are a number of good reasons for excluding Group B fishermen and I do not believe that this is unduly inequitable.

The Pegasus Bay rig fishery has undergone a number of changes since the 1982-83 season. Some fishermen who had only ever fished seasonally up until the end of last season (i.e., Group B fishermen) are now fishing full-time and some who were full-time fishermen are now only fishing occasionally. Some fishermen have ceased fishing altogether. It is not known exactly how many vessels would be left in the fishery if seasonal fishermen were excluded therefore. From what is known about the fishery in the 1983-84 season, the exclusion of seasonal fishermen would leave approximately six or seven vessels in the fishery. This number is reasonably compatible with the number of vessels that the set net TACs are estimated to be capable of supporting and is considered to be an appropriate number of vessels for the fishery in the short term. If there were more than six or seven vessels, then I believe that it would be desirable to remove some Group A fishermen from the fishery.

B. Second step towards attaining the optimum yield

Limiting entry is considered to be an essential first step for attaining the optimum yield in the Pegasus Bay rig fishery. Reducing the size of the set net fleet will not achieve the optimum yield by itself however, as the remaining fishermen would almost certainly continue to target fish for rig. Rig are of a higher value than any other species caught by

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[1] There have been exceptions where some individuals have been granted permits, even though they did not hold a current permit at the time the moratorium took effect.

set net fishermen and with fewer vessels in the fleet, fishermen would probably expect to obtain good catches. Furthermore, with the exclusion of Group B fishermen, the port price for rig would probably increase as rig landings would decline substantially. This would also encourage fishermen to keep target fishing for the species. Other species would probably only be taken as a by-catch and it is unlikely that the entire TACs for these species would be harvested. Thus, rig would still be overexploited and most other species would probably not be fully utilised. The first task for management, therefore, is to divert fishing effort off rig and on to other species. The second task is to ensure that catches of these other species are as close to the estimated interim TACs as possible.

Closed seasons and areas are not considered to be a good means of regulating either the species composition or the size of set net fishermen's catches. To be effective, they would need to reduce rig catches to the smallest possible size, but not inhibit the efficient capture of other species. Any combination of these regulations which was biologically effective would be very complex. It would be difficult to determine and it would be both difficult and costly to enforce and administer. The effects on economic efficiency, fishermen's incomes and conflicts over gear use would not be as severe as those discussed in the previous section, as with fewer vessels in the fleet, competition for the fish would not be as great. Nevertheless, these regulations are not considered to be a feasible or desirable means of controlling catches.

Another possible means of regulating the species composition of catches is to implement mesh size regulations. Ideally, these regulations should be based on some knowledge of the relationship between mesh size and the efficiency with which each species is caught. Very little mesh selectivity work has been done on most species examined in this study. While some mesh selectivity trials has been on rig, the work has not yet been completed. However, through experimentation fishermen will generally find and use the mesh which catches fish with the greatest efficiency. Thus, some useful information may be obtained by examining the mesh sizes which fishermen use to catch each species.

Set net fishermen in the Pegasus Bay area use 228 mm mesh when target fishing for school shark. The major by-catch when target fishing for school shark is hapuku. Very few rig are caught in this sized mesh. Large female rig are sometimes caught, but only occasionally (G. Morris, pers. comm.). By setting a minimum mesh size of 228 mm, therefore, school shark could be harvested efficiently and rig catches would be negligible. This mesh size regulation would result in too much effort being exerted on school shark (and probably hapuku as well), however, and other species (e.g., flounders) would not be fully utilised. It is also unlikely that fishermen could earn reasonable incomes if this regulation was implemented, as school shark are unlikely to be abundant for the full season.

Tarakihi is another species which offers potential to support set net fishermen. Very few set net fishermen have target fished for tarakihi in Pegasus Bay but at Kaikoura set net fishermen target fish for this species with 119-139 mm mesh (Irwin, 1982). Mesh sizes in this range are likely to be too small to catch rig efficiently as most rig would not penetrate the mesh far enough to become gilled. Some juvenile rig would be caught but, providing fishermen were not target fishing for these fish, catches would probably be small. Thus, 119-139 mm mesh would probably catch tarakihi efficiently and at the same time prevent most rig from being caught. Fishermen also use 128 mm mesh when target fishing for flounders and soles and they use 108-139 mm mesh when target fishing for butterfish (Francis, 1979; W. Matthews, pers. comm.; G. Morris, pers. comm.).

It appears, therefore, that rig catches could be greatly reduced if mesh sizes in the 140-227 mm range were prohibited in Pegasus Bay. Such a restriction would not reduce the efficiency with which most other species for which there are set net TACs could be caught. Spiny dogfish and moki would probably not be caught efficiently in nets of this mesh size. This is unlikely to have any serious consequences in the case of moki as this species is not caught in significant quantities by set net fishermen. It may have more significant consequences in the case of spiny dogfish but in the short term these consequences are unlikely to be serious.

Since very few rig are present in the bay between the end of April and the beginning of October, it would not be necessary to have the regulation in force during this time. By allowing fishermen to use mesh sizes in this range during the winter months, it would be possible to reduce enforcement costs and at the same time allow fishermen to target fish for spiny dogfish if they wished. Spiny dogfish prices are highest during the winter months and at present it is the only time that fishermen are likely to target fish for the species (W. Matthews, pers. comm.). In my opinion, therefore, it would not be desirable to have the regulation in force over the winter months.

Mesh size restrictions are frequently regarded as one of the easier regulations to enforce. Relative to some regulations this may be so, but I do not believe that they would be easy to enforce in the Pegasus Bay fishery. Nets are not concentrated into small areas and many fishermen do not bring their nets back to the shore at the end of each fishing trip. Thus, mesh size restrictions could be difficult to police effectively. It would probably be possible to determine whether fishermen were fishing with prohibited mesh, however, by observing the composition of their catches. This could be done at the wharf.

Neither limited entry nor mesh size restrictions set upper limits on the amount of fish which is caught. Limiting entry would reduce the total set net catch considerably as it would reduce both the number of vessels and the incentive to deploy excessive fishing effort. It is still possible, however, that catches of some species could exceed the estimated sustainable catches.

School shark do not appear to be under too much stress in the Canterbury Bight region at present, but since this species is an elasmobranch, it is probably not capable of withstanding heavy fishing pressure. Fisheries for the same species in Australia bear this out (Olsen, 1954 *in* Holden, 1973). There is much to be learned, therefore, from the histories of the Australian school shark fisheries, and from the histories of the local rig and elephant fish fisheries. If the school shark stock is to be spared the same fate as these stocks, then I believe that there is a need to protect it from over-exploitation. Fishermen obtain good prices for school shark and so they may be encouraged to direct a large amount of their fishing effort onto the species if the above mesh size restrictions were implemented. They may not be abundant for long enough to become seriously overfished unless fishermen increased their fishing effort considerably. However, this is not known as yet and so I believe that it would be prudent to be cautious. School shark have a greater potential to support fishermen in the short term than any other species and so the consequences of overexploitation could be severe.

In my opinion, therefore, it would be desirable to introduce a quota for set net catches of school shark. The estimated set net TAC for school shark in Pegasus Bay is 47 t and so a quota of 40-45 t would probably be adequate for the next two or three years. A total quota of this size could probably be enforced. It may induce some extra competition, but since there would probably only be about six or seven vessels in the fishery if Group B fishermen were excluded, the effect is unlikely to be serious in the short term. Even if it did create some added competition for the species, I believe that it would be very wise to have a quota in place.

The need to control catches of other species will depend on the success with which fishermen target fish for school shark. If they target fish for school shark successfully, then other species will probably not be excessively exploited. A large amount of effort could be directed onto these other species, however, if fishermen do not target fish for school shark successfully.

Flounders and soles are not fully utilised in the Canterbury Bight at present. These species are also among the most productive of all New Zealand's commercial species. With only six or seven vessels in the fleet, it is unlikely that there would be serious long-term effects if flounders and soles were fished heavily for one or two seasons. The consequences could be more serious if a large amount of effort was directed onto the tarakihi stock, as tarakihi are already under considerable stress in the region. The state of the region's butterfish stock is unknown and so it is impossible to predict what the consequences would be if a large amount of effort was directed onto this species. The chances that this would occur are very small.

After one or two seasons, it will be apparent whether catches of species other than school shark need to be controlled. For the present, I do not believe that this is necessary. If Group B fishermen were excluded from the fishery, there would probably only be about six or seven set net vessels fishing for these species. The long-term consequences of not regulating the size of catches of these species for the first one or two seasons are not expected to be too serious. The costs of regulating catches of these species effectively would, in my opinion, be higher than can be justified.

An alternative means of diverting fishing effort off rig could be to introduce a rig quota of zero for set net fishermen. This would probably encourage fishermen to adopt similar mesh sizes to those described above and thus it may achieve the same result as mesh size regulations.

In my opinion, a set net rig quota would not protect the rig stock as effectively as the suggested mesh size restrictions. The reason for this is that it would be difficult to determine whether some target rig fishing had occurred if rig was a small but significant portion of the catch. Furthermore, it would be even more difficult to prove that a fisherman had been target rig fishing. While mesh size regulations may be difficult to police, offences against these regulations would be easier to prove than offences against a rig quota regulation. Mesh size regulations would be a greater deterrent therefore, in my opinion. Thus, mesh size regulations are the preferred option.

One of the recurrent problems throughout this entire section of the study has been uncertainty; uncertainty over the accuracy of the TAC estimates, uncertainty over the availability of species, uncertainty over catch compositions, and, therefore, uncertainty over the number of vessels which the fishery can support. Once fishermen have begun to target fish for species such as tarakihi and school shark, then it will be possible to determine how many vessels should remain in the fishery with much greater accuracy. Having determined which vessels it appears to be desirable to retain in the fishery in the short term, however, I believe that there is a responsibility to ensure that these fishermen do not suffer undue hardship while this information is being obtained. For this reason, I believe that a small amount of target rig fishing should be allowed over the next one or two seasons.

The best time to allow set net fishermen to target fish for rig would be during November and December. There are two reasons for this. First, the fish are most abundant at this time (see Figure 2.2). Second, catches during this period are mainly composed of males (see Figure 4.3). Fishermen could earn the greatest profits during this time, therefore, and biological damage to the stock could be minimised. While these catches would still result in stock depletion, they would probably not affect future recruitment greatly as it is unlikely that females would be caught in large quantities.

The purpose of having a short period when rig fishing is allowed is to help ensure that fishermen do not suffer undue hardship. It is to supplement their incomes, therefore, and not to provide them with the main part of their incomes. I would suggest that a period of 4-6 weeks would probably be adequate. This would probably be long enough to enable the fishermen to earn significant profits, and short enough to ensure that they spent most of their time target fishing for other species.

If fishermen knew that there was only a short period in which they could target fish for rig, then they would fish intensively during the period. The consequences of this have already been discussed. Since the open season is only intended to be an interim measure for the next one or two seasons, the economic consequences will probably not be serious. The biological consequences could be more severe, however, if fishing pressure was very heavy during this period. Regulating the length of net which fishermen could use would not be desirable, in my opinion, as it would only incur extra enforcement costs. The regulation is unlikely to be enforceable anyway, as not all nets are set in the same place. It would be preferable, in my opinion, to simply account for the anticipated response when setting the length of the season.

6.4 SUMMARY

If fisheries are to be managed for the greatest possible benefit of the public, then I believe that it is both logical and necessary to accept optimum yield as the goal of fisheries management. Optimum yield is a very complex concept, however. Its elements are many, diverse and conflicting. Since there is no common denominator for all elements, it must eventually be defined by subjectively weighting each element. The weighting assigned to each element will be influenced by the assessor's values and opinions. Thus, different people may describe the optimum yield in different ways. The optimum yield described for this fishery is only my opinion on what the optimum yield is, therefore. Other people may disagree with it.

In my opinion, management must seek to establish a biologically and economically sound base to the Pegasus Bay rig fishery. This seems to me to be the only state in which it is possible to derive the greatest public benefit from the resource. It is also the only state in which those who are dependent on the fishery will be able to earn a reasonable income. Thus I see biological sustainability, economic efficiency and the provision of reasonable incomes for fishermen as three key elements of the short-term optimum yield for the fishery. Cost and complexity must also be key considerations when determining how to manage the fishery to attain the optimum yield. The fishery is very small and it would be difficult to justify complex or expensive management measures.

The total sustainable set net harvest from Pegasus Bay is probably small in the short term. The yield is far less than is capable of supporting all vessels in the existing set net fleet. Thus, it is only by reducing the number of vessels in the fishery that it is possible to establish both a biologically and an economically sound fishery. Reducing the size of the fleet will also make it possible to attain sustainable yields with greater administrative ease and at less administrative cost, as it will reduce competition for the fish. Since most fishermen are unlikely to suffer hardship if excluded from the fishery, I believe that limiting entry is an essential first step for attaining the optimum yield. In order of priority, I believe that full-time set net fishermen should be given access to the fishery before Group A fishermen and I believe that Group A fishermen should be given access to the fishery before Group B fishermen.

From what is known about the fishery in the 1983-84 season, there are a total of about six or seven full-time set net and Group A operations in the fishery at present. This appears to be reasonably consistent with the number that the sustainable set net yields are estimated to be capable of supporting and is considered to be an appropriate number of vessels for the next one or two seasons. If there were more than this number, I believe that it would be desirable to remove some Group A fishermen from the fishery.

It seems likely that Pegasus Bay's share of the Canterbury Bight sustainable rig yield will be harvested by trawlers alone. Trawlers take rig incidentally while target fishing for other species and so their rig catch is unavoidable. Some other species can probably be exploited by the set net fleet without being overfished. Thus the second requirement for attaining the optimum yield in the fishery is, in my opinion, to divert fishing effort off rig and on to these species.

The most appropriate means of diverting fishing effort off rig is considered to be a mesh size regulation banning the use of 140-227 mm mesh in Pegasus Bay between the beginning of October and the end of April. Although this conclusion is based on scant information, it appears that prohibiting mesh sizes in this range would probably prevent fishermen from catching rig effectively, but not reduce the efficiency with which they could target fish for the other major set net species. It would certainly be necessary to examine set net rig landings after the first season if the measure was implemented, however, to determine how effective the regulation had been.

There is a great deal of uncertainty over the accuracy of many estimates provided in this section of the study and over the success with which fishermen can target fish for some species. To ensure that set net fishermen do not face hardship while more information is being obtained, I believe that fishermen should be allowed to target fish for rig for a short interval during November and December over the next one or two seasons. A period of 4-6 weeks may be sufficient to provide the necessary insurance against hardship. Thus, the above mesh size restrictions would not apply during this period.

Diverting most of the set net fishermen's effort off rig and on to other species could place stress on other species. The long-term effects of intensive exploitation over the next one or two seasons by a small number of set net vessels are unlikely to be serious for most species. Since further regulations would only add to the costs of managing the fishery, controls over the catch of most species are not considered desirable in the short term. A set net quota of 40-45 t on school shark is necessary, however, in my opinion. Heavy exploitation of this species for even one or two seasons could have serious long-term effects.

The optimum yield described in this study has been determined by examining the best information which is available at present. There is a great deal of information which is not available, but which is needed to obtain accurate estimates of such things as the number of vessels that the set net TACs can support. I do not believe that it would be desirable to wait until this information is available; first, because management is needed now, and second, because it is only by implementing and monitoring measures such as the above that much of the information will become available. Thus, it is a matter of implementing the best measures that are possible at present. While there may be difficulties and inadequacies associated with the suggested measures they are, in my opinion, better than the alternatives. They are also far better than doing nothing. There is enough information available to know which direction management must proceed to establish a biologically and economically sound fishery and I believe that the suggested measures are a step in that direction.

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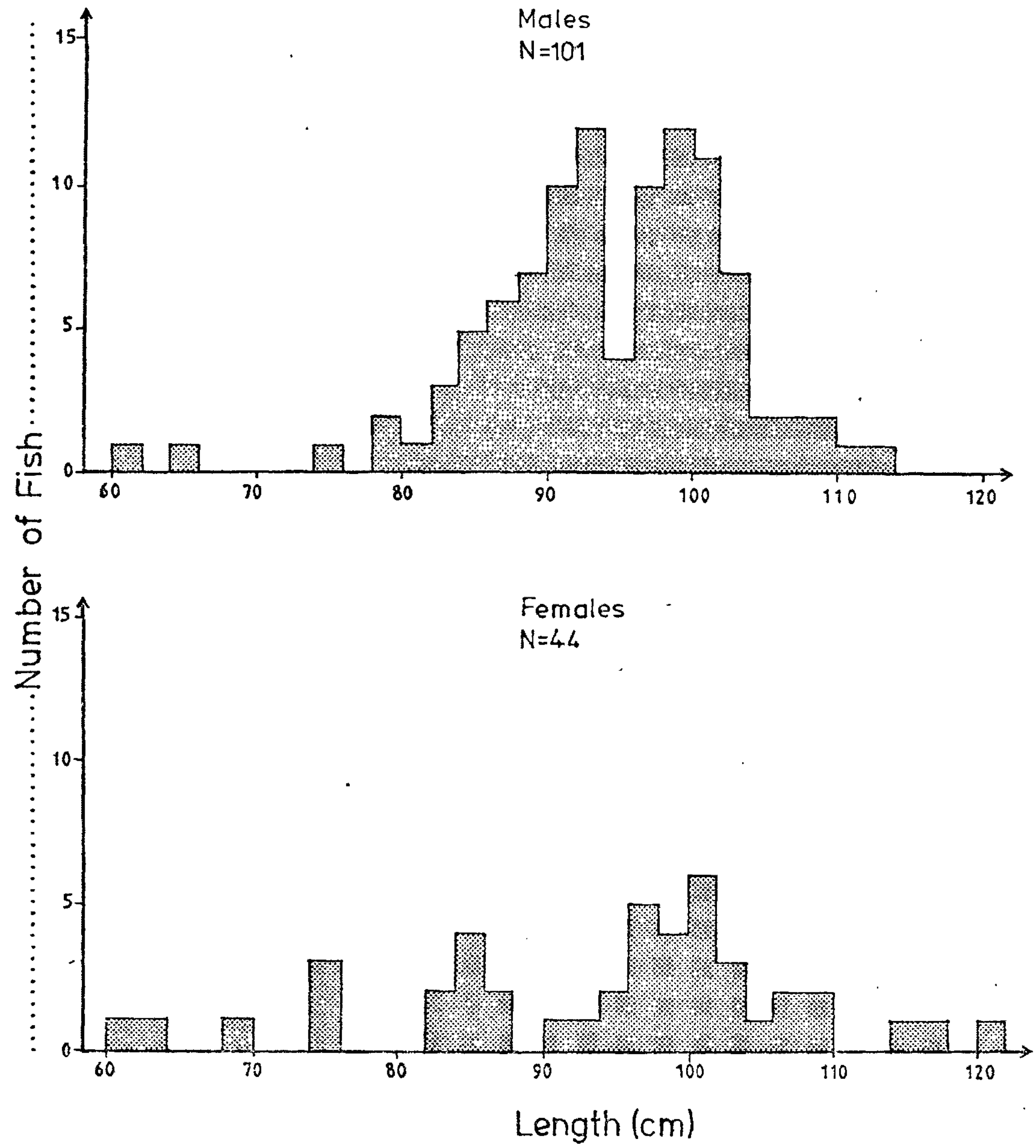
APPENDICES

Appendix 1 Length-frequency distribution (2 cm size class intervals) of male and female rig caught in 165mm mesh set nets in Pegasus Bay , December 1982 - April 1983.



Appendix 2 Criteria used to evaluate rig maturity.
[Source: M. Francis, pers. comm.]

A. MALE

(a) Immature

(i) Claspers do not reach posterior edge of pelvic fins.

(ii) Testes barely distinguishable from epigonal organ.

(b) Maturing

(i) Claspers may extend slightly to well beyond pelvic fins, but are soft and flexible (uncalcified).

(ii) Testes clearly visible, but no larger in diameter than a pencil.

(iii) No semen in seminal vesicle.

(c) Mature

(i) Claspers extend well beyond pelvic fins and are rigid (calcified).

(ii) Testes large with obvious blood vessels.

(iii) Seminal vesicle often full.

B. FEMALE

(a) Immature

(i) Ovary embedded in epigonal organ. Contains only clear, white eggs (no yellow yolk present) of less than pea-size.

(ii) Uteri are thin tubes.

(iii) Nidamental gland (yolk gland) very small.

(b) Maturing

(i) Ovary contains eggs showing signs of yolk formation.

(ii) Uteri may be swollen at posterior ends.

(iii) Nidamental glands developing.

(c) Mature

(i) Ovary contains yolked eggs of pea-size or larger.

(ii) Uteri fully developed.

(iii) Nidamental gland fully developed.

Appendix 3 Criteria used to evaluate female reproductive phase.
[Source: M. Francis, pers. comm.]

(a) Virgin

- Ovary contains eggs of pea-size or larger.
- Uteri developed but firm and sparsely supplied with blood vessels.

(b) Recently ovulated

- Uteri contain one or more eggs but embryos are not visible on them.

(c) Yolked embryos

- Embryos visible on eggs.

(d) Full-term pups

- Large (longer than 20 cm) embryos present. Yolk sacs completely or nearly completely absorbed.

(e) Post-partum

- Uteri empty, but swollen and flaccid. Usually richly supplied with blood vessels.

Appendix 4 Survey of Pegasus Bay rig fishermen.

1. EMPLOYMENT

(a) What do you do for a living in the off-season?

____

Are you self-employed? ______________

(b) Number of crew on the boat (including skipper). ______________

(c) What do the other crew members do for a living in the off-season?

____

(d) Are they/is he/she self-employed? ______________

2. INVOLVEMENT WITH THE FISHING INDUSTRY

(a) How many years have you been rig fishing? ______________

(b) How many years have you been commercially fishing? ______________

3. OWNERSHIP ARRANGEMENT

Please state ownership arrangement, e.g., sole owner-operator, partnership owner-operator, skipper for someone else, other (please explain).

____

4. VESSEL

A. Details of Purchase

(a) Date of purchase ______________

(b) Purchase value of fully equipped boat (excluding nets) $__________

(c) Present replacement value of fully equipped boat (excluding nets)

$__________

(d) Has the engine been replaced since you bought the boat? __________

(e) If so, how long ago? ______________

(f) Purchase value of the new engine you put in the boat $__________

B. Description

(a) Hull — (i) Length ______________________

(ii) Hull material ______________________

(iii) Age of hull ______________________

(b) Present engine — (i) Type of engine ______________________

(ii) Horsepower ______________________

(iii) Age of present engine ______________________

5. GEAR

(a) Purchase value $______________

(b) Present replacement value $______________

(c) Length of net used ______________

(d) Mesh size(s) ______________

6. FISHING COSTS FOR THE ENTIRE 1982-83 SEASON

(a) Fuel and oil $______________

(b) Wages to crew $______________

(c) Vessel repairs and maintenance $______________

(d) Net replacements and repairs $______________

(e) Insurance (annual) $______________

(f) Miscellaneous, e.g., onshore vehicle expenses, mooring fees, etc.

$______________

7. FISHING EARNINGS FOR THE ENTIRE 1982-83 SEASON

(a) Estimated percentage of income from fishing ______________%

(b) Estimated percentage of fishing earnings from rig ______________%

(c) Gross earnings $______________

(d) Any other earnings from fishing (please explain) $______________

____

8. FISHING LOANS

   (a) Total value of fishing-related loans $_______________

   (b) Annual interest on fishing-related loans $_______________

THANK YOU VERY MUCH FOR YOUR ASSISTANCE WITH MY SURVEY. YOUR HELP IS GREATLY APPRECIATED.